APR 2 1931 18

SCIENCE LIBRARY

Vol. XIV, No. 2 PSYCHOLOGICAL REVIEW PUBLICATIONS APRIL, 1931

Journal of Experimental Psychology

EDITED BY

SAMUEL W. FERNBERGER, UNIVERSITY OF PENNSYLVANIA

HOWARD C. WARREN, PRINCETON UNIVERSITY (*Review*)
RAYMOND DODGE, YALE UNIVERSITY (*Monographs*)
WALTER S. HUNTER, CLARK UNIVERSITY (*Index*)
EDWARD S. ROBINSON, YALE UNIVERSITY (*Bulletin*)
HERBERT S. LANGFELD, PRINCETON UNIVERSITY, Business Editor

CONTENTS

The Role of Head Movements in Auditory Localization: P. T. YOUNG. 95
Dextrality as a Function of Age: H. E. JONES. 125
Controls of the Eye-Wink Mechanism: J. PETERSON AND L. W. ALLISON 144
The Correlator: A. FORD. 155
A Study of Eyedness and Handedness: N. B. CUFF. 164
An Improved System of Kymographic Recording: R. G. KRUEGER. . . . 176
An Apparatus for Recording Electrical Changes: H. A. COPELAND. . . 180
Apparatus for Measuring Muscular Tensions: J. B. STROUD. 184
Correction. 186

PUBLISHED BI-MONTHLY
FOR THE AMERICAN PSYCHOLOGICAL ASSOCIATION
BY THE PSYCHOLOGICAL REVIEW COMPANY
PRINCE AND LEMON STS., LANCASTER, PA.
AND PRINCETON, N. J.

Entered as second-class matter, July 1, 1920, at the post-office at Lancaster, Pa.

PUBLICATIONS

OF THE

AMERICAN PSYCHOLOGICAL ASSOCIATION

EDITED BY

HOWARD C. WARREN, PRINCETON UNIVERSITY (*Review*)
RAYMOND DODGE, YALE UNIVERSITY (*Monographs*)
EDWARD S. ROBINSON, YALE UNIVERSITY (*Bulletin*)
S. W. FERNBERGER, UNIVERSITY OF PENNSYLVANIA (*J. of Exp. Psych.*)
WALTER S. HUNTER, CLARK UNIVERSITY (*Index and Abstracts*)
HENRY T. MOORE, SKIDMORE COLLEGE (*J. Abn. and Soc. Psychol.*)
HERBERT S. LANGFELD, PRINCETON UNIVERSITY, Business Editor

WITH THE CO-OPERATION OF

MANY DISTINGUISHED PSYCHOLOGISTS

PSYCHOLOGICAL REVIEW

containing original contributions only, appears bi-monthly, January, March, May, July, September, and November, the six numbers comprising a volume of about 540 pages.

PSYCHOLOGICAL BULLETIN

containing critical reviews of books and articles, psychological news and notes, university notices, and announcements, appears monthly (10 numbers), the annual volume comprising about 720 pages. Special issues of the BULLETIN consist of general reviews of recent work in some department of psychology.

JOURNAL OF EXPERIMENTAL PSYCHOLOGY

containing original contributions of an experimental character, appears bi-monthly, February, April, June, August, October, and December, the six numbers comprising a volume of about 500 pages.

PSYCHOLOGICAL INDEX

is a compendious bibliography of books, monographs, and articles upon psychological and cognate topics that have appeared during the year. The INDEX is issued annually in June, and may be subscribed for in connection with the periodicals above, or purchased separately.

PSYCHOLOGICAL ABSTRACTS

appears monthly, the twelve numbers and an index supplement making a volume of about 700 pages. The journal is devoted to the publication of non-critical abstracts of the world's literature in psychology and closely related subjects.

PSYCHOLOGICAL MONOGRAPHS

consist of longer researches or treatises or collections of laboratory studies which it is important to publish promptly and as units. The price of single numbers varies according to their size. The MONOGRAPHS appear at irregular intervals and are gathered into volumes of about 500 pages.

JOURNAL OF ABNORMAL AND SOCIAL PSYCHOLOGY

appears quarterly, April, July, October, January, the four numbers comprising a volume of 448 pages. The journal contains original contributions in the field of abnormal and social psychology, reviews, notes and news.

ANNUAL SUBSCRIPTION RATES

Review: \$5.50 (Foreign, \$5.75). **Index:** \$4.00 per volume.
Journal: \$6.00 (Foreign, \$6.25). **Monographs:** \$6.00 per volume (Foreign, \$6.30).
Bulletin: \$6.00 (Foreign, \$6.25). **Abstracts:** \$6.00 (Foreign, \$6.25).
Abnormal and Social: \$5.00 (Foreign, \$5.25). Single copies \$1.50.
Current numbers: **Review** or **Journal**, \$1.00; **Abstracts**, 75c; **Bulletin**, 60c.

COMBINATION RATES

Review and Bulletin: \$10.00 (Foreign, \$10.50).
Review and J. Exp.: \$10.00 (Foreign, \$10.50).
Bulletin and J. Exp.: \$11.00 (Foreign, \$11.50).
Review, Bulletin, and J. Exp.: \$15.00 (Foreign, \$15.75).
Review, Bulletin, J. Exp., and Index: \$18.00 (Foreign, \$18.75).

Subscriptions, orders, and business communications should be sent to the

PSYCHOLOGICAL REVIEW COMPANY

PRINCETON, N. J.

Journal of
Experimental Psychology

VOL. XIV, No. 2 APRIL, 1931

THE RÔLE OF HEAD MOVEMENTS IN AUDITORY LOCALIZATION

BY PAUL THOMAS YOUNG

University of Illinois

The present experiment describes an attempt to bring to clear view the rôle of head movement in normal sound localization. The general method has been to detach the 'pinnæ' from the head [1] by means of tubes and trumpets and to fasten the artificial 'pinnæ' to a frame of reference independent of the subject. The arrangement guarantees that head and body movements are ineffective to change the binaural stimulus-pattern.

The work is intended as a control upon a previous study [2] in which the ears were acoustically interchanged by means of a reversing pseudophone.

The experimental work will be presented in four parts. Part I describes a study of the lateral character of the phantom. Part II takes up the problem of binaural direction. Part III is a control experiment upon monaural localization. Part IV is upon the binaural estimation of distance. Follow-

[1] Experiments in which the 'ears' have been detached from the head by means of tubes or electrically have been made by various investigators. See, for example: O. Klemm, Untersuchungen über die Lokalisation von Schallreizen, *Arch. f. d. ges. Psychol.*, 38, 1918, 71–114; E. M. von Hornbostel und M. Wertheimer, Über die Wahrnehmung der Schallrichtung, *Sitzungs. d. Preuss. Akad. d. Wissensch.*, 20, 1920, 388. Some earlier studies by similar methods have been referred to by V. Urbantschitsch in, Zur Lehre von der Schallempfindung, *Pflüger's Arch. f. d. ges. Physiol.*, 24, 1881, 579–585.

[2] P. T. Young, Auditory localization with acoustical transposition of the ears, *J. Exper. Psychol.*, 11, 1928, 399.

ing the experimental work is a general discussion of the problems involved.

I

The lateral character of the phantom.—It is generally agreed that under normal conditions right (R) and left (L) are distinguished with very great precision. Hence a study of the lateral character of the phantom, *i.e.*, its 'on-the-right' or 'on-the-left' character, offers a good starting point for experimentation.

Experimental conditions.—The subject [1] was seated on a stool surrounded by a canvas screen 1 *M* in diameter. During experimentation his eyes were closed and he was ignorant of the arrangement of apparatus. S was instructed to indicate verbally whether the sound was R or L of the median plane.

A head frame with R and L ear-pieces [2] was adjusted. Each ear-piece was connected with a rubber tube precisely 46 cm. long which extended above the head to a hard-rubber sound-receiving trumpet. The trumpets (see Plate I), identical in size and shape with those of our pseudophone, were clamped to a rod with their outer surfaces parallel and separated by 17.3 cm.[3] For convenience we will call the trumpet connecting with the R ear the *right trumpet* and the trumpet connecting with the left ear the *left trumpet*, regardless of their actual positions in space. The imaginary line passing through the central points of the two funnel-shaped trumpet-openings we will designate the *trumpetal axis*. This axis may point up, down, right, left, or in any other direction relative to S.

[1] The subjects were Messrs. G. L. Barclay, C. W. Fox, J. W. Lechay, S. B. Lindley, K. K. Loemker, P. S. Rice. All were assistants in the department of psychology during the year 1928–9. The Ss will be designated by letter respectively: *A*, *B*, *C*, *D*, *E*, *F*. During the year 1929–30 three additional Ss made a few observations: Messrs. W. G. McAllister, L. H. Stott, J. B. Wolfe. Mr. Loemker served as S throughout the entire experiment.

[2] The frame and ear-pieces were similar to those used in the pseudophone (Young, *op. cit.*, 400). The ear-pieces were surrounded with vaseline and tested for sound leakage with a watch. On several occasions library paste was substituted for vaseline (following a suggestion of Prof. Knight Dunlap) but it appeared to have no special advantage over the vaseline and was difficult to remove.

[3] This separation is a few mm above the average interaural distance of the six Ss. From some standpoints the critical value (21 cm) of v. Hornbostel and Wertheimer (*op. cit.*, 389) might have been better.

During the experiment the trumpetal axis was placed in four horizontal and four vertical positions as follows:

(1) Trumpetal axis in horizontal plane above head, R trumpet over R ear and L trumpet over L ear.

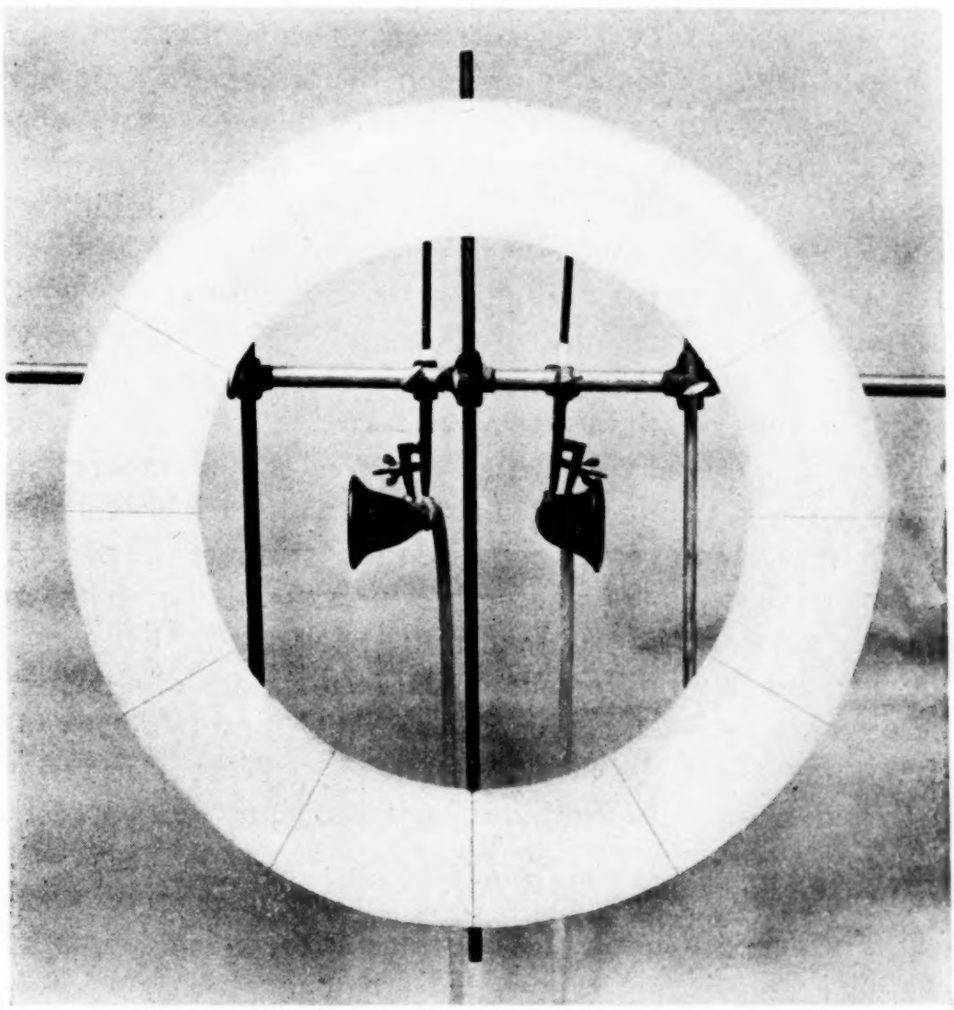


PLATE I. Stimulus-plane and trumpets seen from above.

(2) Same as (1) except that trumpets are interchanged in position.

(3) Trumpetal axis in horizontal median plane above head, R trumpet over chin and L trumpet over occiput.

(4) Same as (3) except that trumpets are interchanged.

(5) Trumpetal axis near left ear in vertical position, R trumpet above and L below.

(6) Trumpetal axis vertical in front median plane, R trumpet above and L below.

(7) Trumpetal axis near right ear in vertical position, L trumpet above and R below.

(8) Trumpetal axis vertical in rear median plane, L trumpet above and R below.

For each of these positions a chance series of 30 presentations—15 R and 15 L—was given to each S. The source was held by E at some point upon the trumpetal axis, never between the trumpets. The distance between source and nearest trumpet was varied in a chance manner from 15 to 100 cm.[1] During the experiment three kinds of stimuli were used: (*a*) the faint double-click produced by make and break of a 4–5 volt current through a telephone receiver, (*b*) the sharp click of a mechanical snapper, (*c*) the tone of a 400 v.d. fork struck by a piano hammer. During any particular series the type of stimulus was uniform.

Results.—When the source was on the trumpetal axis opposite the R trumpet the phantom was invariably localized R. When the source was opposite the L trumpet the phantom was invariably L. The actual position of the trumpetal axis whether vertical, horizontal, front, back, right, left, on the side, etc. made no difference in the result; nor did changes in the distance between source and trumpet, and in the type of stimulation affect the result. Of 1440 localizations (240 per S) R and L were discriminated with 100 per cent. objective accuracy.[2]

Accordingly we conclude that the lateral character of a phantom depends upon the relationship between source and trumpets and is entirely independent of the relationship between trumpetal axis and aural axis. The significance of this result is obvious when the experimental situation is considered physically. A change in the position of the trumpetal axis relative to the head merely bends the rubber tubing without significantly modifying length, diameter, the dis-

[1] The technique of chance variation in the distance between source and trumpet was introduced after preliminary trials had shown that R and L were differentiated with practically 100 per cent. objective accuracy despite such variation.

[2] One exception to the rule is the case of *E* who reported L as R six times when the trumpetal axis was in position 5. In this case, however, the L ear had become plugged with vaseline. After the ear had been cleaned and the apparatus readjusted the series was repeated with the customary 100 per cent. accuracy.

tance between trumpets, or any other physical factor. Hence the position of the trumpetal axis relative to S should not and actually does not have any relationship to the result. The present finding is exactly what might be expected from the standpoint of any of the prevailing physical theories of localization.

Relation to pseudophonic experiment.—The above observations show clearly one of the fundamental principles underlying the reversing pseudophone. There are two axes to be considered—a trumpetal and an aural axis.[1] In the former experiment the trumpetal axis was fastened to the head and moved with it; in the present experiment head movements do not change the trumpetal axis nor the binaural stimulus-pattern.

During the adjustment of the apparatus and between series the Ss occasionally had eyes open and reported dissociation between visible source and phantom. A detailed study of this phenomenon is beyond the scope of the present paper but it may be noted in passing that by directing the trumpetal axis towards any source whatsoever this source may determine a phantom which on purely auditory grounds is localized as either R or L. Thus an indefinite variety of visual-auditory dissociations can be produced. The R–L reversal with the pseudophone involved only one special type of visual-auditory disorientation.[2]

Conclusion.—On a purely auditory basis the R–L character of the phantom depends upon the relationship between source

[1] The fact that we have to consider the two axes separately throws light upon one obscure result in the pseudophonic experiment. I noted (*op. cit.*, 421–2) that under certain conditions the phantom was not displaced exactly 180° by the pseudophone. The irregularity is now seen to depend upon the fact that the trumpetal axis of the pseudophone was displaced by several cm in front of the true aural axis. Rotation of the body under these conditions rotated the trumpetal axis eccentrically about the true auditory center of the head. This eccentricity is sufficient to account for the discrepancy noted. Incidentally, this experiment suggests a method for locating the auditory center of the head.

[2] In a conversation Prof. E. A. Bott suggested that the pseudophonic experiment be generalized, by which he meant that all possible types of visual-auditory disorientation be studied quantitatively and general principles determined. Such a study would involve systematic displacements of the aural axis to various positions and an investigation of the effect of these displacements upon purely auditory localization.

and trumpets. It is entirely independent of the relationship between trumpetal axis and aural axis. When a source is opposite the R trumpet the phantom is invariably localized as R and when a source is opposite the L trumpet the phantom is invariably localized as L.

II

Binaural direction.—If now we explore the space surrounding the detached 'pinnæ,' what relation will be found between the actual position of the source and the apparent direction of the phantom?

First let us look at the question theoretically. In Fig. I,

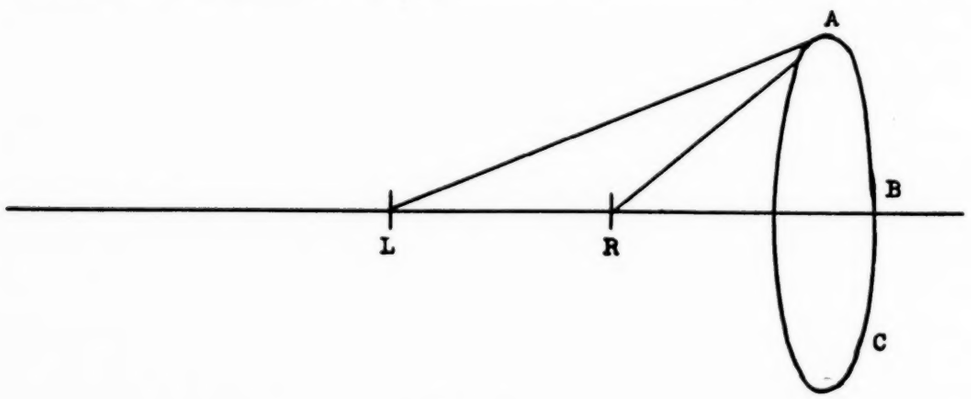


FIG. I.

R represents the R trumpet, *L* the L trumpet, and the line joining *R* and *L* the trumpetal axis. Consider a source located at any point, *A*, in tridimensional space. Sound pressure-waves originating at *A* spread uniformly in all directions, and the physical disturbance at *R* differs from that at *L* in several respects. There is a time-difference between the arrival of the pressure-wave at *R* and *L*; there is an energy-difference dependent upon the fact that the distance *AL* is greater than *AR*; there is a phase-difference between *R* and *L* with periodic vibrations (except for certain frequencies); there may be a difference of wave-form owing to the shape of the trumpets or to the presence of intervening bodies. The relative importance of time-, energy-, phase-, and wave-form-difference is a matter which need not be discussed here.[1]

[1] For a recent statement of a difference-pattern-theory see O. C. Trimble, The relative rôles of the temporal and the intensive factors in sound localization, *Amer. J. Psychol.*, 41, 1929, 564.

A more important consideration follows. Let *A*, *B*, and *C* represent points on the circumference of a circle which lies in a plane perpendicular to the trumpetal axis and which has the axis for a center. Now points on this circumference are strictly equivalent from the physical point of view when considered in relation to *R* and *L*. All points on the circumference should lead to precisely the same localization by S (assuming circular trumpets symmetrically placed about the axis). There is no physical basis for differentiation of *A*, *B*, and *C*; nor is there any reason why S should regard any one of these points as up, down, front, back, etc. A similar argument applies to all other circumferences described about the trumpetal axis on perpendicular planes.

Let us now imagine another plane which passes directly through the trumpetal axis. If this plane be rotated about the axis, any and every point upon it describes a circumference similar to *A*, *B*, *C*. Inasmuch as all the points on any circumference are strictly equivalent physically, it follows that we need consider only one of these points. In other words, our analysis may be restricted to a single plane which passes through the trumpetal axis. The angular position of this plane relative to the axis, whether vertical or horizontal, is a matter of no theoretical consequence.

For convenience we will call a plane which passes through the trumpetal axis a *stimulus-plane*. The plane is determined by three points, one corresponding to the position of the stimulus-object and the others corresponding to the R and L trumpets. According to the above analysis it should not matter whether the stimulus-plane is vertical, horizontal, or intermediate in position provided the trumpets are symmetrical with respect to the axis and other incidental factors are controlled. Significant variables upon the stimulus-plane are (*a*) the distance between R and L trumpets, (*b*) the angular position of the source relative to the midpoint of the trumpetal axis, (*c*) the distances between source and trumpets.

Physically speaking, our problem may be limited to a single stimulus-plane. It is bidimensional.

Experimental conditions.—To explore the space in the region of the trumpetal axis the apparatus diagrammed in Fig. II was arranged. S and E were in separate rooms with a thick wall between them, and S was further enclosed in an inner, partially sound-proof room.

The trumpets were adjusted so that their outer surfaces were parallel and separated by 17.3 cm as shown in Plate I. A circular cardboard disk, 60 cm in outer diameter, was

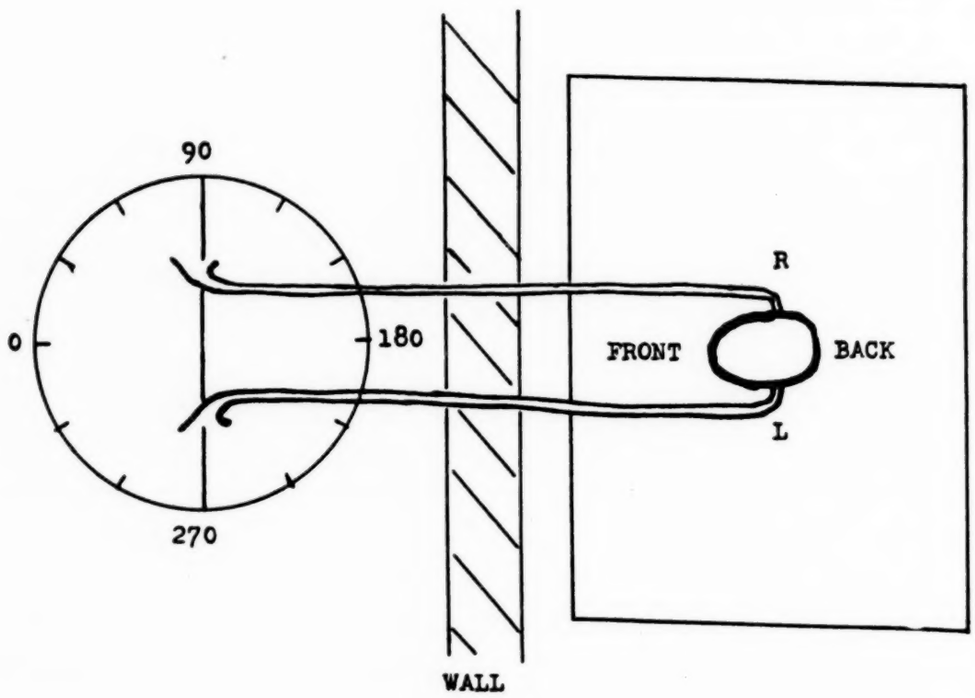


FIG. II.

supported so that one diameter coincided with the trumpetal axis and the center of the circle was the point midway between the trumpets. This disk or stimulus-plane was divided into 30° sectors marked so that 90° was opposite the R trumpet and 270° opposite the L. The source was always placed at one of these 12 division points.

Throughout the experiment the double-click of a telephone receiver when a current of 4–5 volts was made and broken through it served as stimulus. In any given series each of the 12 stimulus positions was used 16 times, the whole in a chance order. Every series was repeated in reverse order and also with the ear-pieces of S's head-set interchanged as regards

R and *L*.[1] This interchange was accomplished simply by crossing the rubber tubes in S's room.

The trumpets (Plate I) were connected to rubber tubes, .7 cm inside diameter and 2 *M* in length, which passed through the walls to the ear-pieces (Plate II). When the

PLATE II. Stethoscope frame and ear-pieces.

ear-pieces were removed S could not hear any sound so the use of vaseline as a means of eliminating sound leakage was discontinued.

[1] The reversal of the stethoscope reveals the extent to which constant errors dependent upon physical inequalities between R and L conducting units, *i.e.* differences in length of tube, sound-absorption properties, obstructions, *etc.*, affect the result. In tabulating results it was necessary to transpose the stimulus-scale 180° when the stethoscope was reversed.

S was given a diagram to aid localization. It showed a circle calibrated by 30° steps with 0° designated 'front,' 90° 'right,' 180° 'back,' 270° 'left.' This served for the horizontal plane and S was instructed to record whether the phantom was above or below the level of the ears. In an actual experiment E would hold the telephone receiver beside the disk at one of the 12 marked positions, call verbally the number of the observation, and then after approximately 1.5″ make and break the current with a silent key. S wrote his localization on a mimeographed sheet prepared for the purpose. A system of electric light signals simplified communication between S and E.

Results.—After several practice series each S was given a complete test series of localizations (384 localizations per S). All 6 Ss localized the phantom consistently in the rear of the head outside of the visual field. Ten localizations for *A* were slightly in front of the aural axis; 9 of these were at 80° and 1 at 70°, points which are outside the visual field or at its very edge. Other series in the experiment gave a similar result.

It would not be feasible to present complete results. Consequently a single series for one subject, *D*, is given, Table I. This is typical of the experiment as a whole with habituated and practiced Ss. The figures indicate that source-positions symmetrically located with respect to the trumpetal axis give approximately the same distribution of localizations. Compare, for example, the localizations for 0 and 180, 30 and 150, 60 and 120, 210 and 330, 240 and 300 degrees. The comparison confirms our theoretical prediction that such pairs of points are physically equivalent.

When the source is on the trumpetal axis, or 30° removed from it, R and L are discriminated with 100 per cent. objective accuracy. This confirms the above experiment upon the lateral character of the phantom.

According to our theoretical analysis the localizations should not change if the stimulus-plane were changed from a horizontal to a vertical position. To test the matter experimentally the stimulus-plane was placed in a vertical position without disturbing the trumpets or other parts of the set-up.

TABLE I

DISTRIBUTION OF SINGLE SERIES OF LOCALIZATIONS FOR SUBJECT *D*, STIMULUS-PLANE HORIZONTAL

Localizations in the range 261–270 are under the column headed 270; those between 251 and 260 are under 260, etc. Left = 270°; Right = 90°.

Position of source	Position of Phantom																	
	270	260	250	240	230	220	210	200	190	180	170	160	150	140	130	120	110	100
0							5	3	7	1								
30											9	5	2					
60													5	4	5	1		1
90													1	2	2	6	1	4
120													3	5	5	2		1
150											8	4	3		1			
180							3	2	4	5	2							
210					1	4	10	1										
240			1	2	2	3	7	1										
270	2	2	1	3	6	2												
300		2	1	6	5	2												
330				1	3	4	6	2										
360 (0)							5	3	7	1								

A complete series was taken for each S. The results show clearly that the position of the stimulus-plane, whether vertical or horizontal, makes no difference.

To illustrate results with stimulus-plane vertical, localizations for *B* are presented in Table II. Tables I and II are

TABLE II

DISTRIBUTION OF SINGLE SERIES OF LOCALIZATIONS FOR SUBJECT *B*, STIMULUS-PLANE VERTICAL

Localizations in the range 241–250 are under the column 250; those between 231 and 240 are under 240, etc. Left = 270°; Right = 90°.

Position of source	Position of Phantom													
	250	240	230	220	210	200	190	180	170	160	150	140	130	120
0						2	5	5	4					
30									3	6	6	1		
60											9	6	1	
90											2	11	3	
120										1	3	8	3	1
150							1		2	4	7	2		
180							5	7	3	1				
210			2	2	7	4	1							
240		1	9	4	2									
270	2	8	6											
300		2	6	6	2									
330		1	1	4	4	5	1							
360 (0)						2	5	5	4					

similar except that the range of localizations in the former is somewhat greater than that in the latter. This difference in range, however, has no discoverable relation to the position of the stimulus-plane.

Taking the experiment as a whole there are well-defined individual differences in the range of the phantom. With *B* the course of the phantom rarely extended to the aural axis; with *A* and *E* localizations were occasionally 10° or more in front of the axis. Furthermore the same *S* varied from series to series which suggests that practice, fatigue, habituation and similar conditions may have some relation to range of localization.

The range of the phantom's course with the stimulus-plane horizontal and vertical is given below.

	A	*B*	*C*	*D*	*E*	*F*
Stimulus-plane horizontal.....	70–270	100–270	90–270	90–270	100–260	90–270
Stimulus-plane vertical.....	90–280	120–250	90–270	90–250	80–280	90–270

The Ss also differ in the displacement of the phantom's course to the R or L. These displacements probably depend upon unequal sensitivity of the ears.

Tables I and II show the position of the phantom in degrees. Due L = 270°; median plane localization = 180°; due R = 90°. The tables do not show the position of the phantom with respect to a vertical axis.

For all Ss the phantom was localized in the back of the head generally at the level of the aural axis or above. The Ss differ in their estimations of the vertical angle. It is interesting to note that prior to the main experiment *A* consistently localized the course of the phantom 'up front,' *i.e.* in front of the aural axis and above its horizontal plane. During the main experiment, however, coincident with a change in conditions,[1] the location of the phantom's arc abruptly shifted

[1] In the preliminary series the stimulus-plane was in the same room with S and above his head. Under these conditions five Ss localized the phantom in the occipital and one (*A*) in the frontal region. When the stimulus-plane was moved to another room as diagrammed in Fig. II all six Ss consistently reported that the course of the phantom was in the occipital region.

from 'up front' to 'rear' and localizations remained in the rear of the head throughout the experiment. It is theoretically important that such a complete change in vertical angle can occur. At present we are in the dark regarding the conditions which determined it.

Control experiments upon the 'in back' character of the phantom.—In the two series described above with stimulus-plane horizontal and vertical, 6 Ss made a grand total of 4608 localizations all of which were outside of the visual field or at its very edge, generally in the rear of the aural axis. Systematic attempts were made to discover physical conditions which would bring the phantom's course directly in front of S. The result of these experiments is negative. A brief report follows.

(*A*) *Angle of trumpets to axis.*—Thompson [1] reported that by varying the angle of his artificial ear-flaps displacements of auditory direction were produced. His observations suggest that the angular relation of the trumpets relative to each other may be a factor conditioning auditory direction. Accordingly several complete series were taken with the trumpets directed at various angles. In one series the trumpets were facing the same direction and in line with the trumpetal axis as in Fig. III-*B*. In another series the trumpets were directed away from each other as the natural pinnæ are, but set at an angle of 45° to the trumpetal axis. A series was taken with both trumpets facing 'forward' with their surfaces tangent to the trumpetal axis. Several asymmetrical arrangements were also tried. The distance between the centers of the trumpets (17.3 cm) was kept constant throughout the experiments.

Despite the above variations in the angular arrangement of the trumpets the phantom was localized consistently outside of the visual field generally behind the vertical plane. There were minor displacements in the direction of the phantom corresponding to the different angular arrangements and these, we have assumed, are dependent upon disturbances of energy ratio.

[1] For details see S. P. Thompson, *Philos. Mag.*, (5) 1879, 8, 385–390; (5) 1882, 13, 411–412. Head movements were involved in Thompson's work.

(*B*) *Distance between trumpets.*—Following a suggestion of Professor K. Koffka [1] the distance between the trumpets was varied. Separations of 20, 30, 40, 50, 60 cm were used and also the smallest possible separation of 3 cm. In addition to the double-click of the telephone a continuous electric buzzer was used for stimulation. These experiments were done during the college year 1929–30 with four Ss (see Note 1, p. 96).

One S sometimes localized the phantom above the aural axis and sometimes in back. For the other three Ss the phantom was consistently in the rear of the head.

When the trumpets were separated by 3 cm the course of the phantom for all Ss was restricted to a few degrees to the R and L of the median plane in the rear. The result indicates that restriction in the phantom's course is related to the separation of the trumpets. [2] There is no evidence, however, that the tendency to localize the phantom in the rear of the head depends upon the separation of the trumpets.

(*C*) *Size and shape of trumpets and ear-pieces.*—In the above experiment in which the distance between the trumpets was varied, a straight conical trumpet, 1.8 cm inside diameter, mounted in a vertical position, was used. For the remainder of the study trumpets of the type shown in Plate I were employed. In series preliminary to Part II straight ear-pieces of the type used in the original pseudophone [3] were employed and in the main investigation the ear-pieces had a 90° bend (Plate II). Despite these changes in the size and shape of trumpets and ear-pieces the phantom remained for the most part in the rear of the head.

Conclusions.—(1) Nine Ss localized the phantom upon an arc resembling a semi-circumference. For seven Ss this arc was invariably in the rear of the head, outside of the field of vision. For two Ss the arc was generally in the rear of the head but occasionally in the upper frontal region. The angle

[1] Prof. K. Koffka has some unpublished data with apparatus similar to our own and suggested that a wider separation of the trumpets might give a frontal localization.

[2] Systematic variation of the distance between trumpets in the range of 0 to 30 cm would doubtless throw much light on the nature of individual differences in restriction of the phantom's course.

[3] Young, *op. cit.*, 400.

with respect to the vertical varies from individual to individual and is independent of the binaural stimulus-pattern (under present conditions).

(2) The angle of the phantom with respect to the median plane is directly related to the angle of the source with respect to the mid-trumpetal plane.

(3) There are well-defined individual differences in the restriction of the phantom's course and in its displacement to the right or to the left.

(4) Systematic attempts were made to discover some characteristic of the binaural stimulus which would give the phantom a localization in front of S, directly in the visual field, or below the aural axis. All such attempts proved futile and we conclude that the distinctions 'up,' 'down,' 'front,' 'back,' *etc.* do not depend upon the binaural stimulus-pattern under present conditions.

(5) Theoretical analysis has shown that when head movements are rendered ineffective to change the binaural stimulus-pattern by the method of detaching the 'pinnæ' acoustically from the head, there is no physical basis for objectively accurate discriminations of up, down, front, back, and intermediate positions. There is physical basis only for discriminations of right, left, and intermediate angular directions. Consequently problems of binaural direction are *physically* bidimensional and may be described on a single plane determined by the two trumpets and the source.

III

Monaural direction.—A control experiment upon monaural localization was made following the work of Part II.

Experimental conditions.—One of the trumpets (Plate I and Fig. II) was removed; the tube was plugged with cotton and dropped between the walls; the holes in the wall were then securely plugged. The other trumpet was placed in the center of the circle with its opening directed towards the 90° point of the scale. Seven stimulus positions were used—90, 120, 150, 180, 210, 240, 270 degrees. Owing to the shape of the trumpet the energy varies from maximum to minimum when the stimulus position varies from 90° to 270°.

The double-click of a telephone was used throughout for stimulation. A series contained 84 presentations, 12 for each of the 7 stimulus positions, the whole in a chance order. Six Ss were given one series for the R ear and one for the L, making a grand total of 1008 monaural localizations.

S wore the binaural ear-pieces (Plate II) exactly as in Part II. The reversal technique merely served to change the stimulated ear from R to L or *vice versa*. In a particular experiment E would speak the serial number of an observation and after a pause of about 1.5″ present the stimulus. S then recorded his localization on a mimeographed blank. He was aided by the chart used in Part II. The Ss were not told in advance that the stimulus would be delivered to a single ear. Nevertheless *A* and *B* guessed after a few trials that this was the case.

Results.—Study of the record fails to show any consistent relation between the position of the source and the position of the phantom. In this respect there is a marked contrast with the work on binaural localization. We have, therefore, disregarded entirely the angular position of the source relative to the trumpetal axis.

A sample of the results is presented in Table III which

TABLE III

MONAURAL LOCALIZATION OF *D*, STIMULUS TO *R* EAR

Column on the left gives position of source and rows show distribution of phantom localizations. The value 40 indicates localizations between 31 and 40 degrees inclusive and 50 indicates localizations between 41 and 50 inclusive.

Stimulus Position	Frequency of Localization in Regions Indicated									
	40	50	60	70	80	90	100	110	120	130
90			1	7		2	2			
120	1		2	5	1	3				
150			3	4		1	2		2	
180	1			2		3	3		3	
210				3		7	1			1
240	1		1	2		2	4		1	1
270			3	6			2		1	

shows the monaural localizations of *D* with stimulus to the R ear. Inspection of this table will show that localizations are

most frequent in the region between 60° and 100° and that all localizations are within the range 40°–130°.

Table IV summarizes the frequency of localization in

TABLE IV

DISTRIBUTION OF MONAURAL LOCALIZATIONS

Subject	Frequency of Localization in Regions Indicated, Stimulus to Right Ear											
	40	50	60	70	80	90	100	110	120	130	140	150
F						84						
B						81	1	2				
C						1	10		20	29		24
E						6	38	10	26	4		
D	3		10	29	1	18	14		7	2		
A	21	23	20	9	3	8						

Subject	Frequency of Localization in Regions Indicated, Stimulus to Left Ear													
	190	200	210	220	230	240	250	260	270	280	290	300	310	320
F									84					
B							1	1	82					
C			12	23		15	24		10					
E						2	3	1	15	37	6	15	4	1
D	4		21	13		28	10		8					
A							1	1	30	28	17	7		

different regions for the 6 Ss. When the stimulus was presented to the R ear all localizations were to the R of the median plane between 40° and 150°, and when the stimulus was presented to the L ear all localizations were to the L between 190° and 320°. Hence R and L are easily and accurately distinguished on a monaural basis. The phantom lies out and away from the median plane for there are no monaural localizations between 150° and 190° in the back nor between 320° and 40° in the front.

Individual differences are great.[1] *F* uses only two categories, 90° (R) and 270° (L). *B* is similar to *F* except that there are a few localizations slightly in the rear of the aural axis. *C* localizes all sounds in the rear of the aural axis—never in the

[1] The Ss differed also in their preference for certain positions on the scale of degrees. This type of irregularity smoothed itself out with practice and with a demand for keener discrimination.

region between 160° and 210°. *E* and *D* localize the sounds both in front and in back of the aural axis. *A* places the phantom most frequently in front of the aural axis. Incidentally he is the S who in experiments preliminary to Part II localized the phantom consistently in front and later changed to localization in the rear.

If we temporarily ignore the wide individual differences (which may be a questionable procedure) and total those localizations which are in front of the aural axis, on the axis, behind the axis, we get the following figures: 290 (front), 427 (on axis), 291 (back). Under present conditions the total group of Ss shows greater tendency towards frontal localization than in Part II.

At the close of each series comments were recorded and these indicate considerable uncertainty and difficulty in determining the direction of the phantom. The phantom was described as something 'vague,' 'diffuse.' *D* reported that 'suggestion undoubtedly played a large part in determining the finer localizations, *i.e.* I could look at the 30° mark on the diagram and could make the next signal seem to originate at that angle.'

The experiment as a whole shows that R and L can be distinguished with great objective accuracy on a monaural basis. From the standpoint of physical science monaural localization is unidimensional, varying from R to L.[1] Apart from mere R and L no cue for direction is given in the monaural stimulus.

Conclusion.—When head movements are rendered ineffective to change the monaural stimulus S can discriminate between R and L, but objectively accurate estimations of direction apart from mere R and L are impossible. Individuals differ markedly in their monaural localizations.

IV

Binaural estimations of distance.—Preliminary experiments with the apparatus described in Part II showed that estima-

[1] Cf. Boring's statement—"It seems that auditory space is primarily uni-dimensional, from one side of the head to the other. Judgments of 'rightness' or 'leftness' are most immediately and most precisely made." E. G. Boring, Auditory theory with special reference to intensity, volume, and localization, *Amer. J. Psychol.*, 37, 1926, 164.

tions of distance were moderately easy and consistent. Consequently we decided to take several series in which S was instructed to estimate the distance of the phantom from the center of the head.

Distance estimations were made in inches for the reason that all Ss were thoroughly familiar with inches and not equally habituated to the metric system. In presenting the results inches have been converted into cm.[1] A yard-stick was placed in S's room for reference; it was used at first but later discarded.

The telephone receiver was held at one of the stimulus positions on the semi-circumference, always at a distance of 30 cm from the center. For each position there were 24 presentations, the whole in a chance order. Half of the presentations were with the ear-pieces in the normal position and half with the ear-pieces reversed.

Two series were taken. In the first the trumpets were arranged as in Fig. III-*A*. In the second series the trumpets

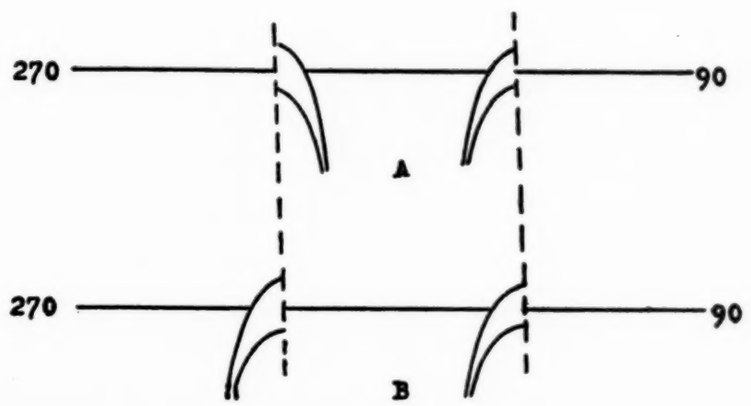


FIG. III.

faced in the same direction as shown in Fig. III-*B*. In both cases the distance between the trumpets was 17.3 cm.

Results.—The range of distances from nearest to farthest is given below. For *C* values less than 3 inches (7.6 cm) were inside the head.

[1] One inch = 2.54 cm; one cm = .3937 inch.

Subject	Range		Mode	
	Inches	Cm	Inches	Cm
C	1–12	2.5– 30.5	3	7.6
B	4–8	10.1– 20.3	6	15.2
F	6–18	15.2– 45.7	10	25.4
E	8–20	20.3– 30.4	14	35.4
A	13–24	33.0– 61.0	18	45.7
D	12–50	30.5–127.0	30	76.2

The average distance and the average deviation for each stimulus-position is shown in Table V. If the data be plotted

TABLE V

AVERAGE DISTANCE OF PHANTOM FROM CENTER OF HEAD AND AVERAGE DEVIATION (IN CM) FOR A CONSTANT STIMULUS, TRUMPETS FACING AWAY FROM EACH OTHER AS IN FIG. III-*A*

Subject		Position of Stimulus						
		90	120	150	180	210	240	270
C	Av.	8.9	8.9	9.4	6.8	12.7	9.4	8.9
	A.D.	1.7	2.4	4.1	3.3	4.3	2.0	1.8
B	Av.	15.2	16.2	15.2	14.2	16.8	14.7	15.0
	A.D.	2.8	3.3	2.8	2.0	2.0	2.0	2.5
F	Av.	19.8	23.4	31.2	31.2	30.0	20.0	18.8
	A.D.	2.3	3.5	6.1	5.6	5.6	2.8	2.3
E	Av.	30.2	34.8	37.3	36.6	36.6	35.3	30.2
	A.D.	4.3	4.8	4.1	5.1	4.3	3.5	2.8
A	Av.	40.9	43.2	47.2	49.8	45.7	43.2	41.4
	A.D.	7.1	6.8	5.8	6.3	3.3	5.8	5.8
D	Av.	65.3	78.7	87.6	82.0	86.9	74.4	57.4
	A.D.	14.2	12.7	11.4	12.7	12.4	15.5	14.7

in the form of curves, the following general principles will be apparent.

(1) The curves are approximately symmetrical about the median (180°) axis.[1]

(2) There are marked individual differences in the estimated distance of the phantom but despite these differences the curves are of the same general type and form.

(3) As the source is changed from 90° to 150° the distance increases; between 150° and 210° the relative distance does not increase and may even shorten so that the phantom comes

[1] Slight irregularities may depend in part upon the unequal sensitivity of the ears.

slightly nearer the auditory center;[1] as the source is moved from 210° to 270° the distance decreases.

Results from the second series are presented in Table VI.

TABLE VI

AVERAGE DISTANCE OF PHANTOM FROM CENTER OF HEAD AND AVERAGE DEVIATION (IN CM) FOR A CONSTANT STIMULUS, TRUMPETS BOTH FACING TOWARDS 90° POSITION AS IN FIG. III-*B*

Subject		Position of Stimulus						
		90	120	150	180	210	240	270
C.....	Av.....	10.2	10.2	12.2	11.2	11.7	10.9	10.9
	A.D.....	2.3	1.3	2.3	2.3	1.8	1.8	1.8
F.....	Av.....	22.9	24.1	29.2	32.2	30.5	28.4	29.2
	A.D.....	1.5	2.3	3.6	3.0	2.7	3.8	3.3
E.....	Av.....	19.3	25.4	26.4	28.4	30.5	25.9	26.7
	A.D.....	2.4	2.8	4.0	5.1	5.3	3.8	3.3
A.....	Av.....	30.0	32.8	33.8	36.8	35.6	37.6	36.1
	A.D.....	3.3	3.3	3.5	3.3	2.5	2.8	3.5
D.....	Av.....	45.0	63.2	72.1	75.0	69.6	71.1	58.4
	A.D.....	11.9	11.9	11.1	6.8	11.9	9.9	8.9

This shows the average distance of the phantom from the center of the head (24 estimations for each position) and the average deviation for a constant stimulus. *B* left the university before the experiment was completed and consequently there are no results for him in Table VI.

Table VI may be generalized as follows:

(1) The curves are asymmetrical. When the source is at 90° the phantom for all Ss is nearer than when the source is at 270°.

(2) There are marked individual differences in distance estimation but the curves are of the same general type.

(3) As the source is changed from 90° to 150° there is an increase in the distance of the phantom. For *F*, *E*, *A*, *D*, this increase continues to 180°. As the source moves from 180° to 270° there is a relative decrease in the distance along

[1] It would be interesting experimentally to determine the shape of curves which would correspond to apparently equal distances for a given constant source. A study of these curves would probably throw light upon the physical basis of distance estimation.

with a good deal of irregularity and marked individual differences.[1]

If Table VI be compared with Table V, it will appear that in the second series (Table VI) *C* and *F* estimated the distance of the phantom as slightly greater than in the first series whereas *A*, *D*, *E*, who originally localized the phantom most remotely, reduced their estimations somewhat in the second series. In other words the Ss are more nearly in agreement about the average distance of the phantom in the second than in the first series. Also variability as shown by the average deviations is less in the second than in the first series. Presumably this tendency towards agreement and uniformity is a practice effect.

Table VI shows that the phantom is nearer when the source is at 90° than when at 270°. Since both trumpets were directed towards the 90° position the maximum stimulus energy was delivered to S when the source was located at this point and the minimum when the source was at 270°. This would seem to indicate that apparent distance of the phantom depends upon the total energy received or possibly upon the binaural energy gradient. In both cases (see Fig. III) the distance between the trumpets was constant so that time relations may be assumed to be the same in both series.

Conclusions.—(1) Distance estimation may be made with moderate ease and consistency under conditions which render head movements ineffective to change the stimulus.

[1] The wide individual differences revealed in Tables V and VI may in part depend upon the ambiguity between loudness and distance. With monaural localization this ambiguity is complete and the same stimulus may give the judgment of a moderately loud 'near up' sound or of a very loud 'far away' sound. With binaural estimations the energy gradient comes into the picture.

In this connection reference may be made to a few observations with a single S. A wooden box was placed in a fixed position relative to the trumpets and struck with a xylophone mallet first very lightly, then moderately, then loudly. The S who knew nothing of conditions was asked to compare the three sounds as regards distance and direction. At first he reported that there was a tendency to localize the loudest sound as the nearest, but after repeated observations he said that there was no change in distance and direction but only in loudness of a sound having a constant position. The experiment was tried a number of times with the box in a variety of positions. The observation raises an interesting experimental problem—under what conditions and within what limits is it possible for a phantom to have a fixed position and still to vary in loudness?

(2) There are wide individual differences in distance estimation, but an indication that practice tends to bring the Ss more nearly to agreement and to reduce variability.

(3) The results indicate a dependence of auditory distance upon energy relations of the binaural stimulus.

(4) The present experimental technique is useful for the study of auditory distance as well as direction.

General Discussion

The rôle of head movements in auditory localization.—Under every-day conditions head and body movements change the pattern of binaural stimulation.[1] Every movement of the head moves the aural axis with respect to a fixed source and this inevitably changes the pattern of stimulation. Psychologists have generally recognized the importance of head movement in auditory localization.[2] But precisely what rôle does head movement play?

Under present experimental conditions the 'pinnæ' were acoustically detached from the head by means of tubes and the apparatus was arranged so that head movements could not possibly modify the binaural stimulus-pattern. A restricted type of sound localization was found which may be described as follows: (1) The distinctions of up, down, front, back and intermediate directions are objectively impossible when head movements are ineffective. (2) S can distinguish R from L and intermediate R–L directions with objective accuracy. (3) The course of the phantom is restricted to an arc outside of the visual field which for normal Ss is generally in the rear of the head at or above the level of the ears. The vertical angle of this arc varies from S to S and has no discovered relation to the binaural stimulus-pattern.

[1] These movements may be reflex as in the startle at an unexpected noise, deliberate as in the search for a hidden or unknown source, or they may be casual movements having no particular relation to auditory stimulation.

[2] For description of bodily movement in the sound localization of infants and animals see J. Meyer, Weitere Beiträge zur Frage der Schallokalisation. Untersuchungen an Säuglingen und Tieren, *Monats. f. Ohrenheilk.*, 46, 1921, 449. J. Fröbes, *Lehrbuch der experimentellen Psychologie*, 1923, I, 376–8. M. Matsumoto, *op. cit.*, 73f. E. A. McGamble, *Psychol. Rev.*, 9, 1902, 372. P. T. Young, *op. cit.*, 425–6, references.

This result has been reported by other investigators with experimental conditions which guaranteed that head movements were ineffective to change the stimulus-pattern. Urbantschitsch [1] refers to some of the earlier observations and states that lack of agreement over the vertical angle of the phantom depends in part on variable factors within the subjects and in part on the tones used. Trimble [2] writes that the 'vertical angle of the transverse plane of the arc' depends upon the method of observation, and upon the auditory habits peculiar to the individual, and may not be regarded as an intensity-, phase-, or time-effect. Banister [3] writes: "In experiments on 'sound' localization, when the ears are stimulated separately, great variations in actual localization are found between individuals: some maintain that the phenomenal effect is that of a source moving round the head in a horizontal plane behind them, others report that it is as

[1] "Wie Silvanus Thompson in neuester Zeit beobachtete, wird die Perception eines Tones, den man mittelst zweier Empfangs-Telephone beiden Ohren gleichzeitig zuleitet, nicht in die Ohren, sondern in das Hinterhaupt verlegt. Nach der Angabe Plumaudon's tritt dagegen das auf die eben angegebene Weise hervorgerufene acustische Bild nicht in der Occipitalgegend, sondern in der Stirngegend auf. Die Beobachtung, dass beim binotischen Hören ein imaginäres acustisches Perceptionsfeld am Occiput erscheint, wurde, wie ich aus der Literatur ersehe, zuerst von Purkyné angestellt, und zwar bemerkte dieser Forscher, dass bei gleichzeitiger Zuleitung eines Tones zu beiden mit Auscultations-Schlaüchen versehenen Ohren, nicht nur in beiden Ohren, sondern auch im Occiput ein acustisches Bild deutlich wahrgenommen wird." V. Urbantschitsch, *op. cit.*, see footnote 1, p. 95.

[2] Trimble's technique was to present the binaural stimulus-pattern from two fixed positions one to the R and the other to the L of S, varying time and energy relations. Under these conditions head movements could not give objectively reliable cues to localization. Trimble's results are probably comparable to those gained by the use of tubes and head-phones so far as the elimination of effective head movement is concerned.

In a letter from which I am permitted to quote, Trimble, basing his statements upon chance observations, writes that the phantom never made its course through the customary field of vision; it was sometimes 'up front' and sometimes 'down rear' and it was in almost every angular position between these extremes. He states that there was no marked tendency towards any particular vertical angle, that each observer had his own habits with regard to the phantom's course, and that the main feature of the phenomenon was its variability. See O. C. Trimble, The theory of sound localization: a restatement, *Psychol. Rev.*, 35, 1928, 516–18; *Psychol. Rev. Monog.*, 38, No. 4, 1928; *Amer. J. Psychol.*, 41, 1929, 564.

[3] H. Banister, in *The Foundations of Experimental Psychology*, ed. C. Murchison, 1929, 298. See also H. M. Halverson, Binaural localization of tones as dependent upon differences of phase and intensity, *Amer. J. Psychol.*, 33, 1922, 178.

though the source moves in a vertical plane, while for others the source seems to move in an intermediate position. All these positions are equally correct interpretations of the auditory sensations. It is an interesting fact that most observers localize the apparent source behind the line joining the ears, and often, especially when telephones are used, inside or very close to the cranium, while blind observers state that it seems as though the source were in front of them—the apparent source is practically never below the level of the ears." And in a footnote Banister adds: "I have only once out of thousands of observations had a report from a normal subject that the source appeared to be lower than the line joining the ears. This was when an observer noticed a tuning fork on the ground. Blind observers will say, 'It is as though the sound comes from a point there on the table in front of me.'" Thus when head movements are ineffective a restricted type of sound localization exists.

A good many of the studies upon sound localization are difficult to interpret on account of the fact that head movement was partly or inadequately controlled. One cannot assume that a head or chin rest of the ordinary variety renders head movement ineffective. A slight movement of a degree or so is sufficient to give a cue to the direction of the source. Klemm [1] reported that in the median plane in front the spatial threshold for noise is rarely over 3° and under the best conditions may be as small as ¾°; in the rear the values are two or three times greater; and in the region of the aural axis the values are still greater. Possibly head movements even less than the threshold values for auditory direction might be effective in determining the position of a source.

In the traditional experiment upon sound perimetry there are 'confusion points' which are physically equivalent or nearly so. Despite the existence of these points, tridimensional localization appears to have an objective accuracy superior to chance. In a recent study by Ewert [2] the localiza-

[1] O. Klemm, Untersuchungen über die Lokalisation von Schallreizen, *Arch. f. d. ges. Psychol.*, 40, 1920, 139–40.

[2] P. H. Ewert, A study of the effect of inverted retinal stimulation upon spatially coördinated behavior, *Genetic Psychol. Monog.*, 7, 1930, 242–4.

tions of three Ss in a sound cage are presented. Twenty-five discrete stimulus-positions were used which the subject localized verbally. Comparing his result with the present one it appears that in Ewert's work (1) there is no marked tendency to localize the phantom in the rear of the head or in any other region, and (2) the percentages of objectively accurate localizations are well above chance and are reliable in three dimensions. A similar generalization may be made on the basis of the work of Matsumoto,[1] and Starch.[2]

In other words when the head is free to move there is little or no restriction in the course of the phantom and objectively accurate localizations in three dimensions are possible. All of the studies on sound localization need to be examined critically from this angle. One should ask "Can S move his head in such a way that the binaural stimulus-pattern is changed?" "Do changes in the stimulus-pattern give possible cues to tridimensional localization?"

In some studies head movements are clearly responsible for a degree of accuracy in tridimensional localization. In the work of Angell and Fite,[3] for example, head movements clearly played a part. One cannot assume that a head-rest clamped to the back of a chair provided adequate control of movement. These experimenters repeated the sound 'often six to ten times, until the subject was satisfied with his judgment.' (!) Under these conditions rapid improvement in the accuracy of monaural localization was found and "A's capacity for localization was in general not greatly inferior to that of binaural subjects. . . ." In view of the present experiment with monaural localization it is safe to affirm that the positive results of Angell and Fite depended upon head movements of S.

Monaural localizations were possible in the experiment with the pseudophone when the head was free to move.[4]

[1] M. Matsumoto, Researches on acoustic space, *Stud. Yale Psychol. Lab.*, 5, 1897,

[2] D. Starch, Perimetry of the localization of sound, *Psychol. Rev. Monog. Suppl.*, 6. 1905.

[3] J. R. Angell and W. Fite, The monaural localization of sound, *Psychol. Rev.*, 8, 1901, 225.

[4] Young, *op. cit.*, 404–5.

With eyes open the localizations were normal, exact, certain, despite the transposition of the single functioning ear to the opposite side of the head. With eyes closed and knowledge of conditions eliminated, objectively accurate monaural localizations were still possible in about 20 percent of the cases and doubtless practice would have given greater objective accuracy. Movement of the head brought about changes in the timbre and loudness of the sounds and these changes served as the subjective basis for localization. The present study shows that when head movement is ineffective to change the stimulus monaural direction has no objective reliability (other than mere R and L) and from the physical point of view monaural direction is meaningless.

Binaural localizations with the pseudophone were similar to those of every-day life apart from the R–L reversal and consequent visual-auditory dissociation. Sounds were localized in front, back, above, below, and in intermediate positions. There was no restriction of the phantom to the rear of the head,[1] nor did it lie on any particular arc. It should be stated, however, that systematic quantitative observations were not made. Ignoring the influence of vision and similar factors it may be said that the only significant difference between the pseudophonic experiment and the present one is that in the former head movements inevitably changed the binaural pattern of stimulation whereas in the latter head movements were entirely ineffective. It should be noted that in both experiments the trumpets were of the same size, shape, substance, etc. In the former experiment they were attached to the head and moved with it. In the latter they were detached and stationary. It is interesting, therefore, that sound localization with the pseudophone resembled the normal, unrestricted, tridimensional type and not the restricted type found when the 'pinnæ' are detached from the head.

All of the above considerations point to the conclusion that when head movements are effective in changing the binaural

[1] When eyes were closed the distinction between front and back still existed. In the median plane (for the one S) a source was generally localized in the rear of the head This suggests the present result. Young, *op. cit.*, 422.

stimulus-pattern the auditory field is unrestricted and coextensive with visual-tactual space, and that objectively reliable localizations are possible in three dimensions. When head movements are ineffective the auditory field is restricted to a single arc outside the visual field and objective accuracy is limited to two dimensions.

The conditions of auditory localization.—In our pseudophonic experiment head movements were not adequately controlled and the present work was commenced as a check. The importance of head movement is now obvious.

Formerly we distinguished three types of sound localization: visual-auditory, auditory, and auditory-motor. The visual-auditory type was really visual-motor-auditory and the relative importance of the visual and motor factors was not studied. The auditory type, with eyes closed and knowledge of conditions eliminated, involved head movements at least as much as in the traditional sound-perimetry experiment in which an ordinary head-rest is used. The auditory-motor type designated a deliberate search for a sounding object. It now appears that other types of movement—such as reflex startle and automatic movement—inevitably change the binaural stimulus-pattern and may play some part in the localization process.

In view of the present work it seems best to give up entirely the notion of *types* and to substitute the view that sound localization depends upon a variety of *conditions*.[1] If the effective conditions of sound localization be represented symbolically by *a*, *b*, *c*, *d*, *e* . . . , then the so-called 'types' correspond to experimental situations in which various groups of these conditions are effective, such as *abd*, *bcde*, etc. The basic problem for experimental psychology, then, is to determine the essential conditions upon which auditory position (distance and direction) depends.

[1] In discussing the conditions of localization Meyer distinguished between a series of mediate factors, vision, touch sensations ('*sensitive Empfindungen*'), habituation, experience, and an immediate factor given directly by the sense of hearing itself. J. Meyer, *op. cit.*, 450–451. In this connection see also: K. Goldstein und O. Rosenthal-Veit, Über akustische Lokalisation und deren Beeinflussbarkeit durch andere Sinnesreize, *Psychol. Forsch.*, 8, 1926, 329f.; R. Allers und O. Schmiedek, Über die Wahrnehmung der Schallrichtung, *Psychol. Forsch.*, 6, 1924, 92–112.

If we view the matter from the standpoint of the external stimulus, two considerations are important: (1) whether the stimulus be monaural or binaural, and (2) whether or not head movements can change the stimulus-pattern.

Regarding the second point it is interesting to note that a change of stimulus-pattern can be produced either by head movements when the source is at rest or by a moving source when the head is at rest. In the first case S experiences a phantom in a fixed position; in the second case S experiences a moving phantom. In the present experiment a moving source always gave a moving phantom. There is a relativity here which suggests the familiar railway illusion.

From the standpoint of physiological psychology basic problems center around the nature and mechanism of sound localization and localization in general. The previous studies of Stratton, Klemm,[1] and Young have shown that a visual-motor adjustment towards a sounding source may evoke normal sound localization despite visual-auditory disorientation. More recently Ewert [2] has reported a series of experiments in which the visual field was rotated by a system of

[1] Klemm has described an experiment similar in method and result to our own. The ears were acoustically interchanged by means of tubes. The description is given in a single paragraph which follows: "Ich brachte zunächst vor die beiden Ohren Zinkresonatoren und leitete den linken mit einem Schlauch nach dem Gehörgang des rechten Ohres, den rechten ebenso in das linke Ohre. . . . Ich stellte daher vor die nach vorn gerichteten Resonatoren je einen Schallhammer auf und liesz diese in rhythmischer Folge abwechselnd links und rechts schlagen. Schlosz nun der Beobachter die Augen, so hörte er die Hammerschläge gekreuzt. . . . Jetzt öffnete man die Augen und folgte möglichst aufmerksam den Bewegungen der Hämmer. Den Gesichtswahrnehmungen erlag die gekreuzte Lokalisation: der linke Hammer klopfte wirklich links, der rechte rechts. Wenn der Beobachter in dieser neuen, also dem tatsächlichen Intensitätsverhältnis widerstreitenden Lokalisation nach einigen Minuten ganz sicher geworden war, schlosz er wieder die Augen. Und nun blieb eine Zeitlang, etwa während fünf bis acht Schlägen, die neu gebildete, dem Intensitätsverhältnis widerstreitende Vorstellung erhalten, bis sie allmählich mit zwingender Gewalt in die alte, also dem Intensitätsverhältnis entsprechende, zurückkehrte. Heirmit war zwar eine Nachwirkung jener unter der Herrschaft der Gesichtsvorstellungen gestifteten falschen Zuordnung nachgewiesen. Um diese aber genauer zu studieren, muszte man die Vertauschung leichter in der Hand haben." Klemm then changed over to an electric, microphone apparatus for interchanging the ears and performed similar experiments. He reported the same result as regards the effects of vision and attention to the visible source. O. Klemm, Untersuchungen über die Lokalisation von Schallreizen, *Arch. f. d. ges. Psychol.*, 38, 1918, 94–5.

[2] *op. cit.*, see footnote 2, p. 119.

lenses after the manner of Stratton. The subjects learned to localize the sound despite the 'distraction' of the visible source. Ewert's work shows that visual observation of a source influences the localization of sound, but that visual dominance is not an inevitable result of visual-auditory disorientation. The all important factor is the subject's set or *Aufgabe*.

Further study of the rôle of head movement in sound localization needs to be made along present lines. The 'pinnæ' could be attached to the head in various positions and then detached from the head. The experiment would throw more light on the problems raised in the present paper.

Conclusion

Acoustical detachment of the 'pinnæ' from the head renders bodily movements ineffective to change the binaural stimulus-pattern. Under these conditions reliable tridimensional localization involving discriminations of up, down, front, back, *etc.* is impossible. The binaural stimulus-pattern, however, furnishes a basis for discriminations of right, left, and intermediate directions.

With head movements ineffective the phantom's course is restricted to an arc which for normal Ss is outside of the visual field. Under present conditions this arc was generally in the rear of the head. The Ss differ regarding the vertical angle, range, and R–L displacement of the arc.

Under present conditions S can estimate with moderate ease and self-consistency the distance of the phantom from the center of the head. Individuals differ in distance estimation but the results indicate that practice tends to bring about greater uniformity.

The experiments demonstrate a technique useful for distinguishing between the external physical conditions and the purely physiological conditions of sound localization, and for studying the rôle of such factors as head movement and vision in the localization of sound.

(Manuscript received May 5, 1930)

DEXTRALITY AS A FUNCTION OF AGE

BY HAROLD ELLIS JONES[1]

Institute of Child Welfare, University of California

Genetic studies of handedness have been variously concerned with (*a*) methods of testing and of classification, (*b*) the familial incidence of left-handedness, (*c*) phenomena of reversed handedness in twins, (*d*) the influence of training, and the technique of changing left-handedness, (*e*) the relation of handedness to other developmental variables (intelligence, speech, mirror-writing, motor skills, etc.), and (*f*) the quantitative expression of dextrality. The present report is concerned with the last of these problems, and particularly with the description of quantitative dextrality changes in relation to age.

Functional and anatomical indices of handedness.—Numerous methods are available for determining indices of right-hand function. Whipple,[24] reporting on dynamometric data 'for an ordinary group of school children,' stated that the strength of the left hand averages from 91 to 96 percent of the strength of the right; the relative strength of the favored hand increases with age. "The superiority of one hand over the other is evident when the child enters school, but becomes increasingly evident as maturity approaches, and especially at puberty, so that a heightened difference in the strength of the hands may be regarded as one of the characteristic indications of pubertal change."

In dynamometer tests of a group of 57 children, 3½ to 13 years of age, B. J. Johnson[7] found a left-hand superiority in eight boys and eight girls. A year later the proportion of dextrals had increased to such a degree that only one of the boys and none of the girls made a higher left hand score.

When dextrality indices were computed over a wide age range (6 to 81 years), Woo and Pearson[25] found no correlation between age and difference in strength of grip. Their sample included over 3000 cases (males) from Galton's 1884 data. From the somewhat meager information furnished by this single dynamometric measurement, they concluded that 'experience does not tend to train sinistralists into dextralists.'

The comparative efficiency of the left and right hands in tapping, as measured by the ratio of the left to right, is reported by Wells[1] to average .90 for adults. Smedley[1] found that the ratio increases from .82 at age of nine to .89 at age of 18 (indicating a diminishing disparity of the two hands).

For a tracing test, Bryan[1] has reported somewhat similar results, finding a reduction in right-hand superiority after puberty. Among preschool children, however,

[1] Acknowledgments are due to Dr. Adele S. Jaffa and Mrs. May Yeoman Townsend for assistance in data collection, and to Mr. H. S. Conrad for statistical assistance.

Wellman [23] states that the superiority of the right hand increases from three to six years. From Wellman's original data, the writer has computed indices for 41 cases and correlated them with chronological age. In the case of the tracing board, correlations of the order of −.3 were obtained between C. A. and the index L/R. This was true whether the scores were in terms of point of first contact, or in terms of the percent of the line within the path. The correlations suggest a slight tendency for the relative efficiency of the right hand to increase with age, but the P. E.'s (.09) are too high for complete reliability. In the case of the tracing path, the indices showed no relation to age. In another preschool group (60 children, three to five years, tested with the Young Slot Maze A) McGinnis [14] has reported that the older children tend to use the right hand to a greater degree than the younger children, and with fewer changes from right to left.

From data on a peg board test given by W. F. Jones [9] to 25 right-handed and 25 left-handed boys on each of five age groups, the writer has computed the following indices (L/R).

DEXTRALITY INDICES FOR TAPPING

Age Group	Right-handed Subjects	Left-handed Subjects
8	.778	1.259
10	.811	1.159
12	.888	1.128
15	.895	1.052
18	.933	1.038

The peg-board data, in agreement with Smedley's records on tapping and Bryan's on tracing, indicate a diminution of manual differences during adolescence. In a more difficult test it is of course possible that reverse results might be obtained.

An interesting form of dextrality index has been described by Bauer,[3] who considers that the degree of overestimation of weights by a given hand indicates the degree of dominance of the other hand. Tests of various other types of motor control have also been used in a comparison of the preferred and non-preferred hand. For the most part, however, these have accomplished little more than to suggest further experiments in technique. In the use of most of the simpler unimanual tests which have been employed, the chief source of error lies in the fluctuating results obtained under changing motivation. With the dynamometer, for example, Binet and Vaschide (reported in Whipple [24]) found that a slight increase in incitement could result in the non-preferred hand excelling the performance of the preferred hand.

The most recent report in this field is that of Heinlein [13] who gives the results for 60 children, age 4 to 12, on a series of tests including grip, tapping, steadiness, and aiming. Cumulative records, at year intervals, were obtained for a decreasing proportion of the children. When the total group was classified as 'consistently right-handed, consistently left-handed, and inconsistent,' it was found that the first of these groups showed an age increase in dextrality in the tapping and target series, while the second group showed an age increase in dextrality in steadiness and grip, but a decrease (more marked left-hand superiority) in the target test. The 'inconsistent' group showed no significant age changes in dextrality. The data are not in a form to permit a fuller quantitative statement.

An anatomical index of handedness developed by W. F. Jones,[10] involves a determination of left and right proportions in certain arm, hand and digital measurements. As tested by Beeley,[4] this has yielded results unfavorable to the validity of the anthropometric method as an index of handedness.

[1] Summarized in Whipple.[24]

Handedness in infants.—Watson [20] has made an attempt at a quantitative record of handedness in infants by attaching physiological work adders to the left and right hands. He reported "the method has not as yet yielded any very decisive results." In a later publication, however, he advances the statement, "The main problem is, I believe, settled: Handedness is not an 'instinct.' It is possibly not even structurally determined. It is socially conditioned." [22]

Another type of handedness test, not usually employed to yield a quantitative index, involves a median-line presentation of a series of toys and implements, with a record of manual preference in reaching, and of the preferred or dominant hand in unimanual and bimanual activities. Observations of the preferred hand have been made in infancy, under more or less controlled conditions.

J. M. Baldwin [1] experimented with an infant tied to a chair by a cloth around the body; colored papers were presented at various distances on a level with the shoulder. Beginning at about the 7th month, a preference was shown for the right hand in connection with movements which required vigorous reaching.

Woolley [26] reported the appearance of a definite right-hand preference at 7½ months in reaching, and in 'all ordinary activities' by the end of the 9th month. The only training factors known favored the use of the left rather than the right hand. On the basis of this case she concludes: "So far as their application to theory is concerned, the tests are one more proof of the already accepted view that right-handedness must be a normal part of physiological development, not a phenomenon explicable by training."

Major,[15] again reporting on one case, found that the preference shifted back and forth, until in the 12th month a slight preference for the left began to appear and increased rapidly. Dearborn [5] also found a shifting preference, which became stabilized into a right-hand preference at about the 20th month. Watson [21] reported on the eye-hand coördinations of an infant who was tested from the 80th to the 171st day. She used the left much more than the right hand, although when tested again at 2½ years she was definitely right-handed.

M. C. Jones [8] has reported on over 500 observations of handedness preference in infants from 80 to 300 days of age: "As part of the routine procedure in testing for thumb opposition and reaching, the reactions of the two hands were noted separately. *At the stage where these functions were developing no preference was found for one hand rather than the other*, except in a very few cases. Case *C* had a spastic right paralysis, and of course used the left hand only in reaching and grasping. Case *D* was given 10 trials on each of three successive weeks (at 173, 180 and 187 days). Both thumbs were opposed, but his reaching movements were always made with the left hand. The mother and father were both left-handed. In the remaining case the parents were both right-handed, but the child (at 132, 162 and 203 days) used only the left hand in reaching. It is interesting to note that a short time previously he had received a very severe burn on the left hand, without affecting his persistent preference for it."

Gesell [11] has illustrated a device for demonstrating preferential handedness: "Three suspended bells confront the child in the sitting position. One bell is in the median plane, one in the left hand plane, and one is in the right hand plane. The child's spontaneous address to and exploitation of this situation gives some clue to the fluctuations and dominance of right hand preference at different age levels." In another paragraph he states,[12] "Under extremely diverse . . . social suggestions, we have found that the great majority of infants . . . show a progressive tendency toward right handedness which becomes well established in the second half of the first year."

Meyer [16] regards the development of right-hand preference as an expression of the maturing dominance of the left hemisphere. The right hemisphere, serving simpler functions, is assumed to mature earlier, and hence left-handedness in early infancy is a necessary accompaniment of right-handedness in later life. Beyond stating that 'the left-handedness of infancy is commonly enough observed,' he gives no genetic data in support of this theory.

An age increase in dextrality is assumed by those theories which regard handedness as secondary to a unilateralization in some other trait, as in sighting,[17] or the space sense of corresponding halves of the retinas,[18] or the adjustment to visceral weight distribution, etc. These theories are unsupported by adequate genetic data. A number of studies have reported an age decrease in the percentage of left handed children,[1] but for the most part these are based on too small a battery of measurements, and in some cases on tests which have a changing significance at different ages.

The evidence is in favor of an increasing dextral lateralization during infancy and, less conclusively, up to six years of age. With pre-adolescents conflicting results have been obtained, while among adolescents several studies have shown that the difference between the two hands is beginning to diminish. It is, however, apparent that the relation of dextrality to age may vary not only with the age range, but also with the specific function tested, and with the method of computing the dextrality index.

A dextrality index based upon the work of the two hands in 'free activity' (as in Watson's work adder experiments) is somewhat different in principle from the indices which are derived from unimanual tests assigned to the two hands in succession. The former measure has the advantage of being adaptable to a wider range of activities, and presents a picture of the relative output of energy in the two hands under normal conditions. The latter index provides a clearer expression of the relative capacities or efficiencies of the two hands in certain circumscribed tasks. In any comprehensive study of handedness, no doubt both of these types of record are needed, as well as records of (*a*) subjective choice, (*b*) objective

[1] Thus Ballard,[2] in groups of over ten thousand, reports 4.1 percent sinistrals, age 4 to 14, and only 2.7 percent sinistrals, age 8 to 14.

primacy and (*c*) analyses of dextrality 'types.'[6] It appears desirable, also, to consider the use of the hands not merely in classificatory test situations, but also in longer term studies which will give an account of sequential activity, and of the temporal shifts in hand preference.

The data to be reported on the following pages are derived from a study of work ratios in a preschool group; the basis of measurement is the time during which each hand is active in the performance of a series of motor tests, the tests being so devised as to permit the use of either or both hands.

> For this purpose the writer has employed a Bristol activity recorder, consisting essentially of a strip chart with a battery of ink pens applied horizontally to the chart. The paper is pulled by a Seth Thomas spring movement at a rate of six inches per minute; the time in seconds can be read from parallel cross lines spaced 1/10 inch apart. The perforated margins of the paper engage in the sprockets of a roller; a constant speed is possible, through the application of the power at this roller instead of at the winding spools. A secondary spring movement, connected with the terminal spool, keeps the paper taut and prevents buckling under the ink pens. The pens are operated by electromagnets, line current being employed with a 60-cycle 6-volt transformer; a common return wire leads to the electromagnets from the transformer, and individual wires lead to telegraph keys which close the circuits.

With this equipment, observations have been made on 60 children. It was of course desirable that the children should be observed in standard situations, which would furnish a variety of stimuli for hand movements, and which would emphasize discriminative motor adjustments rather than gross or forceful activity. Situations of this nature are provided by the ordinary performance tests which occur in the Gesell and Merrill-Palmer series, and which have the further advantage of giving interpretable measures of motor efficiency.

The Tests

The following tests were selected:

A. Wallin peg-board A. Six round pegs were placed in two piles near the edge of the board farthest from the child, and on each side of the midline. Then, "See if you can put them back in their holes." Three trials were given, the record for the quickest trial being used in later statistical treatment.

B. Seguin form-board. The board was placed on the table with the side containing the star nearest to the child. The forms were arranged in the standard fashion prescribed by Stutsman, in two piles at the left and right of the

board. Then, "Let me see how quickly you can put these back in their places." The child's attention was held to the task by opportune comments, without telling him to hurry. Records were used for the best of three trials.

C. The Pink Tower. The tower was built behind a screen and then placed in front of the child. After giving the standard Merrill-Palmer directions, the tower was knocked down with the blocks scattered but near the child. A failure to build the tower (occurring in three cases) was marked F and time records were not included in the averages. If a tower was built of incorrectly placed blocks, the case was included, since the number and type of manipulations were usually equivalent to those made in a successful effort at building.

D. Color sorting. The child was shown four glasses, each containing six colored pegs. The examiner lifted the first glass, saying, "See, this glass has pegs that are all of the same color . . . they are all alike," emptying them on the table. A similar procedure was followed for the glasses containing the blue, red and green pegs. After the pegs were mixed thoroughly, they were placed in a pile in the midline in front of the child and he was told, "Now you are going to put them all back in the glasses where they belong."

E. Whitman form-board. The board was placed on the table in front of the child, with five yellow pegs on one side and five blue pegs on the other. Then . . . "Now you may put these pegs in any holes you wish to." The pattern was recorded, as well as the handedness and time data.

Tests A, B and E emphasize speed and delicate eye-hand coördinations. Test B requires a variety of fine adjustments in slipping and twisting blocks into the proper spaces; the blocks are so large that they may be grasped by the whole hand, or by two hands. In A, and more particularly in E, the pegs are small and light, and their placement requires repetition rather than variety of movement. Test C involves the balancing of blocks in a stable tower, a task suitable to the use of both hands, with one dominant and the other holding the blocks already placed. Test D involves the simple coördinations of picking up and dropping pegs, and in comparison with the other tests requires very little precision of movement.

The Sampling and Procedure

The subjects examined were children in the nursery school of the Institute of Child Welfare, and in the Children's Community, a coöperative nursery school in Berkeley. Thirty-three boys and twenty-seven girls are included in the sample; the age range is from 18 to 66 months; median 38.5 months, mean 39.4 months, S.D. 10.5 months. In connection with other studies, 54 of the 60 children had given adequate

coöperation in a number of intelligence tests, each child receiving an average of over six tests. The average of their 'average I. Q.' is 119.8, median 120.0, S.D. 14.5.

The handedness tests were administered by an examiner (Dr. A. Jaffa) with whom they were already acquainted, and who, on previous occasions, had given them other tests in the same room. A second observer sat behind a one-way vision screen and manipulated three telegraph keys as follows:

Key 1: locked shut at the beginning of each test, and opened at the end. (The total time for each test was also taken by stop-watch, and was used as a check on the adjustment of the strip recorder.)

Key 2: depressed whenever the subject began to use his right hand, and held down as long as this hand remained overtly active.

Key 3: the same, for the left hand.

When the hands were used together, keys 2 and 3 were pressed down simultaneously. With a little practice, it was possible for the observer to employ a touch system with the keys, and to have his other hand free for writing. A pad was mounted conveniently before him, making notations possible concerning the relative efficiency of the two hands, and the nature of the conditions which stimulated their alternate use.

From the records obtained in this manner, the participation of each hand can be traced in temporal patterns, 'when' and 'how long.' Since the strip recorder has capacity for ten pens, additional keys may at any time be added to the instrument board, to mark the relation of the hand movements to specific elements in each task, or to symptoms of tension or distraction in the subject. In connection with a further study it would no doubt be desirable to register primacy of movement (which hand initiates a specified process); dominance (which hand takes the lead in bimanual activity); and the relationships of visual control (eye-hand or hand-eye sequences).

The 60 children have been divided into four groups on the basis of C.A. These groups are substantially equivalent in

I.Q.'s, sex proportion and social status. Their time means on each test are given in Table 1.

TABLE 1

TIME MEANS (IN SECONDS) FOR EACH TEST FOR EACH AGE GROUP [1]

	N	C. A. Range	Test A		Test B		Test C		Test D		Test E	
			Mn	A.D.	Mn	A.D.	Mn	A.D.	Mn	A.D.	Mn	A.D.
Group 1.....	16*	18–30 mos.	26	8	119	62	44	30	91	30	110	37
Group 2.....	15	31–37 mos.	18	2	95	35	30	13	73	21	73	16
Group 3.....	15	38–45 mos.	15	3	59	24	17	8	73	20	59	19
Group 4.....	14	46–66 mos.	13	3	41	7	12	3	60	10	55	15

*N = 13 for Test B, and 15 for Test C.

For the total battery of tests, the correlation between speed and C. A. is .70 ± .046.

	Test A	Test B	Test C
Percent within age range of Stutsman's norms [19]...	27	84	59
Percent of above equalling or exceeding Stutsmann's 50 percentile.....	50	81	71

Before making this comparison, Stutsman's norms were smoothed, by eye. This smoothing provided an interpolation for all intermediate age, and is preferable to an ordinary straight line interpolation between the values given by Stutsman at six-month intervals.

DEXTRALITY RATIOS [2]

With reference to problems in handedness, the data obtained in this series of tests are adapted chiefly to the comparison, on the basis of time, of the quantitative use of the two hands. For this purpose three different kinds of dextrality ratios were employed.

D_1 gives the proportion between the total right-hand time and the total time of test performance, and is no doubt the most logical expression of degree of dextrality. D_2 eliminates

[1] Three of the handedness tests were administered and scored in such a manner as to permit comparison with external norms. Such a comparison is given in the accompanying table, in order to provide some further indication of the characteristics of the sample.

[2] The term 'dextrality' is in this report always used in the fixed sense of 'right-handedness.' Thus, a sinistral is characterized by a low dextrality ratio. Somewhat misleadingly, the term is used by some writers to signify the degree of dominance of either hand over the other, depending on which is the preferred hand.

all the time in which either hand was used in bimanual activity; it is the proportion between the (unimanual) use of the right hand and the total time in which the right or left hands were used unimanually. D_3 gives a double weighting, in the denominator, to the bimanual time. If R is used to denote the time the right hand was used unimanually; L the time the left hand was used unimanually; and B the time both hands were used together, these three ratios may be expressed as follows:

$$D_1 = \frac{R + B}{R + L + B},$$

$$D_2 = \frac{R}{R + L},$$

$$D_3 = \frac{R + B}{R + L + 2B}.$$

As applied to some activities, any dextrality ratio may at times give a faulty measure of the work accomplished by each hand, owing to the fact that the non-preferred hand may be slower and more awkward in its movement. Thus, tasks are conceivable in which the right hand might increase its dominance in point of function and production, while the dextrality ratio (based on time) might diminish. This has not occurred in the tests now under consideration.

Table 2 gives the dextrality means, by age groups, for the five tests taken together.

TABLE 2

DEXTRALITY MEANS—TOTAL BATTERY[1]

	D_1		D_2		D_3	
	Mean	A.D.	Mean	A.D.	Mean	A.D.
Group 1	.677	.169	.649	.185	.613	.152
Group 2	.692	.158	.639	.152	.642	.136
Group 3	.757	.170	.760	.166	.737	.158
Group 4	.816	.140	.729	.121	.692	.125

[1] Owing to the negative skew in the distribution of dextrality ratios, the average ratios would of course be higher if computed in terms of median or mode, instead of in terms of the mean.

In D_1 a steady increase in ratios may be noted from one group to another. This may be summarized as follows: Under the conditions of the experiment, the average child of about two years of age uses the right hand 2/3 of the time. The proportionate use of the right hand increases, until in four old children the right hand is used 4/5 of the time. The dextrality ratios D_2 and D_3 are less regular, showing a drop instead of an increase from the 3rd to the 4th age groups. This may be attributed, however, to the effect of an increasing bimanuality. The three measures of dextrality have been found to correlate with each other to a degree of approximately .9 (from .90 to .92). They exhibit similar correlations with age and efficiency, but noticeably different correlations with the bimanuality index $\left(\frac{B}{R+L+B}\right)$. For this reason, in further statistical treatment it has been deemed advisable to partial out bimanuality before discussing the relations of an index of dextrality with other variables. For ordinary purposes it would appear that the ratio D_1 is more suitable than the others, since it is less affected by changes in the degree of bimanuality in successive age groups. Subsequent tables will, therefore, include only measures based upon D_1.

Since the total battery includes tests of a diverse character, it is desirable to consider the dextrality ratios for each test taken separately.

TABLE 3

DEXTRALITY MEANS BY TEST

	Test A		Test B		Test C		Test D		Test E	
	Mean	A.D.	Mean	A.D.	Mean	A.D.	Mean	A.D.	Mean	A.D.
Group 1	.682	.237	.593	.174	.719	.250	.713	.224	.705	.206
Group 2	.661	.346	.695	.172	.769	.205	.777	.195	.578	.156
Group 3	.832	.236	.673	.231	.859	.114	.763	.253	.681	.236
Group 4	.905	.150	.715	.151	.914	.88	.820	.151	.744	.163
Total group	.766		.671		.814		.766		.676	

In tests B and E, as previously stated, the blocks (or pegs) were divided into left and right piles and placed on opposite

sides of the boards; this would be expected to encourage the use of a non-preferred hand, for blocks adjacent to that hand. In the other tests, the objects to be manipulated were placed close to the median plane. A further difference exists between certain of the tests which involve a considerable degree of motor effort, fine coördination, and adjustment to obstructions, and Test D in which these elements are not present. In spite of these differences in external conditions and in the nature of the tasks, the various tests showed no very marked differences in the average dextrality ratios.

Tests B and E run fairly consistently lower than the others, no doubt for the reasons indicated above. In each test the tendency is apparent toward an age increase in the dextrality ratios. In the distribution of these ratios, a slight tendency toward bimodality can be seen, or towards a plateau when the data are plotted in terms of percentile curves. (Fig. 1.)

Sample Case Records

A number of subjects showed very constant dextrality ratios in the various tests; the average deviation, however, for the ratios within a test series, was nearly .20. The following sample records were obtained for a pair of twins, forty-five months of age:

	Richard				Nancy			
	Time in Seconds				Time in Seconds			
	Right	Left	Bimanual	D_1	Right	Left	Bimanual	D_1
Test A.....	0	14	0	.00	10	4	0	.71
Test B.....	12	40	4	.25	29	0	0	1.00
Test C.....	11	8	1	.61	6	1	0	.85
Test D.....	15	39	0	.27	50	5	0	.90
Test E.....	29	15	0	.65	23	21	0	.52
Total.....	67	116	5	.37	118	31	0	.82

The total times were closely similar, but while one used the right hand only 34 percent of the time, the other used it 82 percent of the time. Richard writes left-handed and throws a ball left-handed, while Nancy uses her right hand in all of the unimanual tests. In sweeping, Richard holds his

right hand nearer the business end of the broom, but the burden of the work appears to fall upon the left. Nancy is

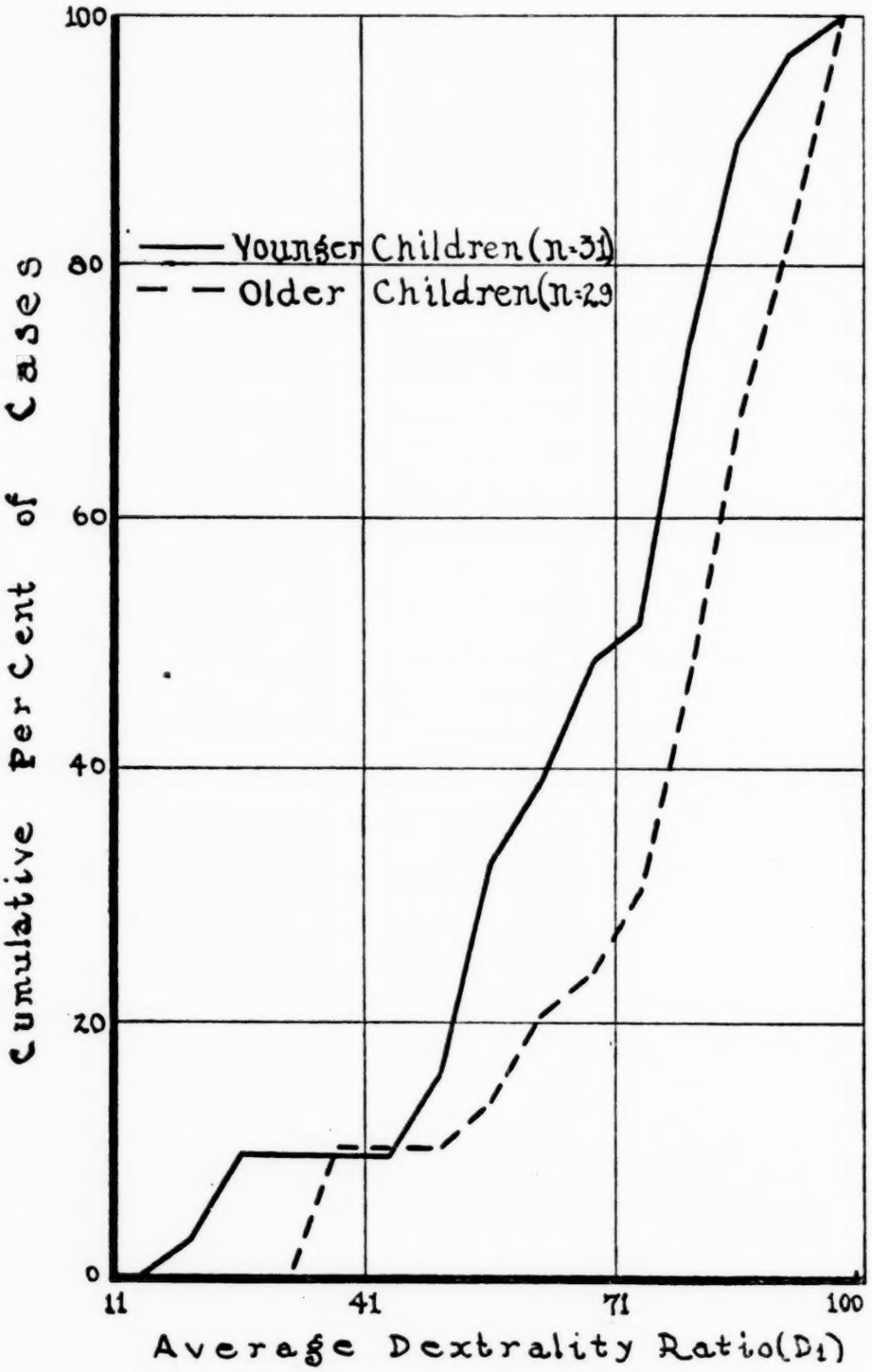


FIG. 1. Cumulative frequency curves. Average D_1 of younger vs. older children.

of the RRL type, emphasizing the left hand only in the minor bimanual activities.

Correlational Analysis

The average of 10 intercorrelations of D_1 in the separate tests is .41. While this coefficient is low, it must be remembered that it is based on tests having an average time of less than one minute (see table 1). It may be permissible to regard this correlation as of the nature of a reliability coefficient for fifths of the total test battery. If, then, we apply the Spearman-Brown prophecy formula, the reliability for the entire battery becomes .77. This figure is almost certainly too low, since the individual tests should correlate with themselves (upon re-tests) higher than they correlate with each other. The detailed data are given in the accompanying correlation table.

TABLE 4

Intercorrelations of the Dextrality Ratios for Separate Tests

	A	B	C	D	E	Av.
A	.....	.43	.48	.37	.40	.42
B	.....	.....	.35	.50	.50	.45
C	.....	.....	.....	.29	.40	.38
D	.....	.....	.....	.....	.37	.42

If now we apply the correlational method in studying the relationship of dextrality to age, we obtain the following results:

TABLE 5

Dextrality Correlated with C. A., by Tests

Test A	.26 ± .081
Test B	.15 ± .087
Test C	.28 ± .081
Test D	.14 ± .085
Test E	.09 ± .086
Total battery	.24 ± .082

The correlations are fairly consistent in indicating a positive but low relation between dextrality and age. Corrected for attenuation, a coefficient of the order of .3 would be obtained. Before interpreting this, however, certain other relationships need to be considered. A tendency was found for bimanuality to increase with age. In the youngest group,

the two hands were used together only 11 percent of the time. In the oldest group, this rose to 23 percent, the correlation between age and bimanuality being .20 ± .084. (Bimanuality, as here defined, takes account merely of the simultaneous activity of the two hands in a common task, without reference to functional inter-dependence. Bimanual tasks are conceivable in which a high degree of mutual function is involved, with alternating rather than simultaneous use of the two hands. This, however, was not the case in the test situations employed in this experiment.) When bimanuality was analyzed in relation to function, the following table was obtained:

TABLE 6

BIMANUALITY IN THE SEPARATE TESTS, FOR THE TOTAL GROUP

	Mean	Median	S. D.	n
Test A	.081	.07	.223	60
Test B	.106	.071	.129	57
Test C	.258	.143	.299	59
Test D	.125	.34	.209	60
Test E	.082	.14	.144	60

The smallest degree of bimanuality was registered in the pegboards, where the two hands were used together only 8 percent of the time. The largest degree was found in the case of the Pink Tower, where the left hand frequently functioned as a 'helping hand' in holding the lower blocks in the structure, while the right hand was performing the active work of completing the tower.

We are now in a position to undertake a fuller correlational analysis of the variables which have been considered. Let the variables age, speed (efficiency), dextrality and bimanuality be denoted 1, 2, 3, and 4 respectively. The zero order correlations are given in the following table.

	1 Age	2 Speed	3 Dextrality	4 Bimanuality
1, Age	.....	.70	.24	.20
2, Speed	.....	.....	.27	.11
3, Dextrality	.....	.....	.....	.21

The following partial r's may then be derived:

Dextrality by age:

Bimanuality constant, $r_{13.4} = .21$.

Dextrality by bimanuality:

Age constant, $r_{34.1} = .17$.

Dextrality by speed:

Age constant, $r_{23.1} = .14$.

Bimanuality constant, $r_{23.4} = .25$.

Age and bimanuality constant, $r_{23.14} = .15$.

Speed by age:

Dextrality constant, $r_{12.3} = .67$.

Bimanuality constant, $r_{12.4} = .69$.

Dextrality and bimanuality constant, $r_{12.34} = .67$.

Speed by bimanuality:

Age constant, $r_{24.1} = .04$.

Dextrality constant, $r_{24.3} = .06$.

Age and dextrality constant, $r_{24.13} = .07$.

With the exception of the age-efficiency correlations, the coefficients are low, and conclusions obtained from them will have meager reliability. There is some evidence that dextrality bears a slight relationship to efficiency, even when other relevant factors are held constant. The relationship of speed to age is not to any significant degree dependent upon the increase of dextrality with age.

A subsidiary question which may be of interest concerns the extrapolation of dextrality ratios below the ages actually tested. We have seen that at 24 months the average ratio is approximately .66, increasing to .80 at 54 months. At what age would we expect the average ratio to equal .50—indicating an impartial bilateral function? On the basis of the regression of dextrality on age, we may estimate a ratio of .59 at six months and of .56 at birth. (In terms of median or mode, the ratios would be appreciably higher.) This may possibly signify that if tests comparable to the present series, but adapted to lower age levels, were used in early

infancy, they would show a slight average tendency toward right hand dominance, as early as any test results are obtainable. Such a conclusion, however, would involve a somewhat extreme forcing of the available data.

The increase of dextrality with age is open to several interpretations:

1. With increasing age, children may be better motivated in the tests, and under the influence of a stronger 'goal' idea may use the superior hand more consistently. If this were the case, however, it should be reflected in the records of interest and coöperation shown in the tests. In motor tests of this type a definite age coöperation factor is not revealed within the age range studied.

2. With older children the tests diminish in difficulty, and may be conceived as permitting an orderly and systematic use of the preferred hand, rather than a flurried alternating or bimanual attack. The influence of such a factor is not supported, however, either by observations of the younger children's methods and attitudes, nor by the bimanuality index, which, as we have seen, becomes greater, rather than less, with increasing age. Within the difficulty range of our tests, it appears probable that decreasing difficulty would favor an increasing use of the non-preferred hand—a factor which no doubt accounts in large measure for the results reported by Smedley, Bryan, and W. F. Jones.

3. The reported increase in dextrality is based merely upon population averages. It is possible that the majority of the children retain a stable ratio, and that the average increase is due to the 'dextralization' of left-handed children. Results from other tests, and from developmental data, do not support this theory. It is recognized, however, that a better method of approaching our problem would be through cumulative records on the same children, rather than through cross section averages.

4. The increase in dextrality may be limited to a narrow range of test functions, and may not reflect a general increase in right-hand dominance. In reply to such a supposition, it should be stated that right-hand dominance is best regarded in terms of specific tasks, and that the concept of a 'general

dominance' is probably invalid. The tasks chosen in the present series offer a fairly wide variety of requirements. Supplementary data from other tests are, however, to be desired.

5. The increase in dextrality is the result of a training process; in the test series it is affected by transfer factors from the numerous motor performances of everyday life, in which children give a greater amount of exercise to their preferred hand, and thus progressively strengthen their performance.

6. The increase in dextrality is primarily due to maturation, and is a symptom of a progressive left hemisphere dominance or of some other lateralization process, with implications in the total developing organization of the body.

Our data offer no very effective clue to a choice between (5) and (6); much less do they enable us to judge as to the genetic origin of right-handedness in environmental or intra-organic influences. These involve problems which cannot be met except on the basis of an experimental 'longitudinal' study, or (as will be seen in a later report) from data on twins.

The Relation of Dextrality to Mental Age

From the average I.Q. (see page 131, above) each child's M.A. at time of testing was computed, and this was correlated with D_1 of the total battery of handedness tests. The resulting r (.24) is the same as the correlation of D_1 and C.A., which is not surprising in view of the fact that C.A. and M.A. are themselves correlated, in our sample, to the extent of .90.

Sex Differences

The mean D_1 for 27 girls was .775 and for 33 boys .709. The chances of a true difference are 91 out of 100. This difference, however, would be slightly greater if a correction for C.A. were made, since the boys average nearly six months older than the girls. For the individual tests the most marked sex differences are in test E, .769 as compared with .645, with a fully reliable female superiority. There is some indication that the degree of sex difference is a function of age, for the correlation of $D_1 \times$ C.A. is $.48 \pm .10$ for the girls, and $.18 \pm .11$ for the boys. Furthermore, if the boys and girls

are divided into approximately matched pairs on the basis of chronological age, and the average C.A. of the pair correlated with the algebraic pair difference (D_1 female $- D_1$ male), an r of $.38 \pm .11$ is obtained. These correlations, which need to be confirmed on a larger number of cases, suggest a more rapid tendency for unilateralization in girls than in boys; this is in conformity with the supposition of a greater rate of physiological maturing in girls during this period.

Summary

1. A series of five handedness tests were given to 60 preschool children, ages 18 to 66 months. The tests were chosen to present a variety of requirements as to difficulty and fineness of coördination; all could be performed unimanually, or by the use of the two hands together or in alternation. An activity timer gave a quantitative record of incidence and duration in the use of the two hands.

2. A dextrality ratio was computed, indicating the proportion of the total time that the right hand was used in test performance; in successive age groups the ratios for the total battery increased as follows: .677, .692, .757, .816. In spite of marked differences in the nature of the tasks, average ratios for the separate tests were closely similar.

3. An average intercorrelation of .41 was obtained for ratios in the separate tests, indicating a minimum reliability of .77 for the total battery.

4. Bimanuality ratios ranged from .081 to .258 in the separate tests (registering the proportion of the total time that the two hands were used together).

5. Chronological age was found to correlate .70 with speed, .24 with dextrality, and .20 with bimanuality. Mental age also correlated .24 with dextrality.

6. Partial coefficients indicate (with incomplete reliability) that dextrality bears a slight relationship to efficiency (speed) even when other factors are held constant.

7. The correlation of speed by age was not significantly reduced when dextrality and bimanuality were held constant.

8. Dextrality ratios for girls tended to be higher than for boys, and the rate of increase with age was higher for girls.

These differences were incompletely reliable, but are in agreement with the supposed faster maturation of girls.

References

1. Baldwin, J. M., Origin of right- or left-handedness, *Science*, 1890, **16**, p. 247.
2. Ballard, P. B., Sinistrality and speech, *J. Exper. Ped.*, 1911–12, **1**, 298–310.
3. Bauer, J., Untersuchungen über die Abschätzung von Gewichten unter physiologischen und pathologischen Verhältnissen. Ein Beitrag zur Kenntnis der Rechts-und Linkshändigkeit, *Zsch. f. d. ges. Neurol. u. Psychiat.*, 1911, **4**, 290–326.
4. Beeley, A. L., *An Experimental Study in Left-handedness.* University of Chicago Press, 1918.
5. Dearborn, G. V. N., *Moto-Sensory Development.* Baltimore, Warwick and York, 1910, 212 pp.
6. Downey, J. E., Dextrality types and the preschool child, *27th Yearbook Nat. Soc. Study Educ.*, pt. 2, 1928, 153–158.
7. Johnson, B. J., *Mental Growth of Children.* New York, E. P. Dutton, 1924, p. 45.
8. Jones, M. C., The development of early behavior patterns in young children, *Ped. Sem. & J. of Genetic Psych.*, 1926, **33**, p. 577.—
9. Jones, W. F., The problem of handedness in education, *Report of Nat. Ed. Assoc.*, 1915, 959–963.
10. Jones, W. F., A study of handedness, *Publ. Univ. of Southern Calif.*, 1918.
11. Gesell, A., *Infancy and Human Growth.* New York, MacMillan, 1928, p. 48.
12. Gesell, A., *op. cit.*, p. 368.
13. Heinlein, J. H., A study of dextrality in children, *J. of Genetic Psychol.*, 1929, **36**, 91–119.
14. McGinnis, E., The acquisition and interference of motor habits in young children, *Genetic Psychol. Monog.*, 1929, 6, No. 3, 209–371.
15. Major, D., *First Steps in Mental Growth.* New York, MacMillan, 1906.
16. Meyer, M., Left- and right-handedness in infancy, *Psychol. Bull.*, 1913, **10**, 52–109.
17. Parson, B. S., *Left-handedness.* New York, MacMillan, 1924, pp. 179.
18. Stevens, H. C. and Ducasse, J., The retina and right-handedness, *Psychol. Rev.*, 1912, **19**, 1–31.
19. Stutsman, R., Performance tests for children of preschool age, *Genetic Psychol. Monog.*, 1926, **1**, pp. 67.
20. Watson, J. B., *Psychology from the Standpoint of a Behaviorist.* Philadelphia, J. B. Lippincott Co., 1924, p. 262.
21. Watson, *op. cit.*, pp. 296–302.
22. Watson, J. B., *Behaviorism.* New York, Peoples' Institute Publ. Co., 1925, p. 102.
23. Wellman, B. L., The development of motor coördination in young children, *Univ. of Iowa Stud. in Child Welfare*, 1926, **3**, p. 86.
24. Whipple, G. M., *Manual of Mental and Physical Tests.* Baltimore, Warwick and York, Part I, 1914.
25. Woo, T. L. and Pearson, K., Dextrality and sinistrality of hand and eye, *Biometrika*, 1927, **19**, (1 & 2), 165–199.
26. Woolley, H. T., The development of right-handedness in a normal infant, *Psychol. Rev.*, 1910, **17**, 37–41.

(Manuscript received May 5, 1930)

CONTROLS OF THE EYE-WINK MECHANISM

BY JOSEPH PETERSON AND L. W. ALLISON

George Peabody College

The operation of the eye-wink mechanism is an important object of study in psychology because of the ease in observing and recording objectively one's blinks, and also because of the great susceptibility of these eye-lid responses to influence by various mechanical and social factors and therefore the variety of their controls at different levels. The main control of the eye-blinks seems to be autonomic (or intra-organic), the most direct center of control being in the striate body (Ponder and Kennedy, 1927). In this and in other respects these activities resemble breathing. While reflex mechanisms doubtless play a minor rôle—less indeed than was formerly supposed—it is obvious that, under different sorts of stimuli, they may modify considerably the regularity and rate of blinking. Blinking rate and regularity are also, as Ponder and Kennedy have shown, functions of emotional conditions. And, finally, winking may be regulated 'voluntarily' or by rather direct social stimuli, both verbal and non-verbal. This direct voluntary control is especially important to psychologists because of the rôle that language factors and earlier learning generally play in it. Voluntary winks as well as suspensions of blinking are manifested both as immediate and as delayed responses to social stimuli of a very wide range of complexity and degree of directness of excitation. Such 'voluntary' interferences with normal blinking seem never to originate 'spontaneously.'

Preliminary experiments by the senior author showed that after training and careful instructions, several persons (we have used four) may silently count the blinking of one individual through a given period of time with a high degree of agreement. This method of silent counting is useful not only in cases of investigating the blink responses when the subject

is unaware of the fact and is left free from direct social influences and from certain artificial conditions imposed in the laboratory, but also as a check on the accuracy of certain objectively recording devices. It is very serviceable when the subjects are either human infants or animals. (A portable polygraph, as used by Ponder and Kennedy, is, of course, better when the distribution of individual blinks is desired.) When the silent-count method is used it is best to have a cumulative stop-watch, starting it (in a concealed place) one blink before each count begins, and stopping it when the last count is made. The total period of time can then be noted afterwards, so that the subject will not be affected by the stop-watch, or suspect that he is under observation.[1]

To secure objective records from which the several inter-blink periods may be obtained a simple electric recording device is essential (Cason, 1922). For our work a 'spectacles' frame was made of heavy wire 3 mm in diameter, and it was bent to conform to the shape and size of the heads of the several subjects. When once fitted these 'spectacles' remain relatively stable in position and are not uncomfortable. To the left frame is soldered a small rectangular loop 6.5 cm long and 1 cm wide, projecting outward horizontally. This served as a support for a small lever made of copper wire 0.5 mm in diameter and 9 cm long, nearly balanced on the support. One end of this lever is attached to *S*'s left eyelid, just above the free margin, by means of a small piece of adhesive plaster about 2 by 8 mm. The lever is so light when properly adjusted that, after a few minutes of adaptation, the subject is unaware of its movement with the eyelid. The other end of the lever is adjusted to a position of about 3 mm

[1] A little training enables one to count one's own blinks rather semiautomatically, using the stop-watch as indicated. The counting itself then goes well enough, but the senior author (Peterson) has noted in himself and has elicited also from others a tendency now and then to 'slip back' on the *tens* count, so he may repeat 50's, *e.g.*, after reaching 59, or may otherwise get off on the changes in the 10's counts. However, one can learn to be mildly on guard at these critical counts. More direct concern about this, of course, influences the blinking rate perceptibly. The authors have both noted on themselves blink impulses at about the normal rate even when the eyes are closed. Whether these can be shown by objective means to occur on non-self-observing *S*'s is still a question. Checks on the validity of automatic-self counting have not yet been made in sufficient quantity to report results.

beneath a switch when *S*'s eye is open in the normal position. Closure of the eyelid brings the distant end of the lever into contact with this switch thereby closing the circuit and causing an electric marker to record on the kymograph drum the eyelid closure. A simultaneous time-record in units of 1 sec is made with a Jacquet chronometer. All the recording apparatus was kept in another room not immediately adjacent to the one in which *S* was seated. By means of a telegraph key, with sounder in *S*'s room, *E*, after giving preliminary instructions, signaled to *S* when to start or stop. Records were used in non-voluntary responses (blinks) only after *S* had had time to become adapted to the situation. It is not contended, of course, that the *S*'s were wholly unaware of, or influenced by, this artificial situation.

The first part of our experiment concerns the effects on the blinking rate of different sorts of mental preöccupation. Those tried were (1) reading a section in Carr's *Psychology*, (2) cancelling the *a*'s, *e*'s, *i*'s, *o*'s, and *u*'s, in a standard printed cancellation sheet, (3) fixating the top of the aerial mast of a radio broadcasting station, approximately a half-mile distant, and (4) fixating a small dot on a white card (6 × 6 cm) attached to the wall at a distance of about one meter from *S*'s eyes. Seventeen college women students were used as *S*s.

TABLE 1

SHOWING MEAN INTER-BLINK PERIODS IN DIFFERENT MENTAL PREÖCCUPATIONS

	Mean	σ	σ_m	Size of critical ratios ($d/\sigma d$)
1. Reading.....	13.94	6.12	1.485	
2. Cancellation.....	26.32	14.80	3.323	m_2–m_1, 3.42 [2]
3. Distant fixation...	21.06	10.44	2.290	m_3–m_1, 2.61; m_2–m_3, 1.30
4. Near fixation.....	13.12	5.20	1.261	m_1–m_4, 0.42; m_2–m_4, 3.71;[2] m_3–m_4, 3.04 [2]
5. Unoccupied, see Table 2.....	3.90 (about)	1.72	.960	

[2] Difference of means is statistically reliable.

The results are shown in Table 1, which gives the mean number of seconds of the inter-blink periods for the different kinds of mental preöccupation. It is seen that the mean inter-blink period while the *S*s are reading is 13.94 ± .99 sec.

and that when they are cancelling letters it is 26.32 ± 2.22 sec. During distant fixation this mean is 21.06 ± 1.52 sec, while with near fixation it is only 13.12 ± .84 sec. The standard deviation of the distributions and of the means are also given in the table, as well as the critical ratios (d/σ_d) of the differences between means. Those differences which are statistically reliable are starred in the table. A reliable difference is shown between the inter-blink periods of reading and cancellation, between distant fixation and near fixation, and between cancellation and near fixation. The difference between mean inter-blink periods in the cases of reading and distant fixation very nearly reaches the point of reliability. With more *S*s it would doubtless also have met the criterion. The means for reading and near fixation are practically equal. These data show very clearly that the blinking rate is influenced by different kinds of mental activity in the subjects and probably also by different degrees of strain in accommodation, by eye movements, etc.; and they agree in the main with the results by Ponder and Kennedy, who have also shown that the inter-blink period is markedly increased under certain conditions of emotional stress. It is possible that modifications in the blinking rate are far more significant of emotional states than are records of galvanic changes. This problem needs investigation, and may prove to be a valuable one in certain applications. The ease of getting one's record unknown to him is an important consideration. But this method requires careful training and scientific caution on the part of the investigator.

TABLE 2

THE INTER-BLINK PERIOD IN RELATION TO AGE, SEX, AND PREÖCCUPATION

Age	15 through 19		20 through 24				40 through 70			
Sex	F	F	F	M	F	M	F	M	F	M
Mental activity...	Not reading	Reading	Not reading		Reading		Not reading		Reading	
No. cases.....	17	17	17	5	17	5	8	4	8	4
Inter-blink period in sec.....	3.98	5.50	3.73	3.90	4.41	4.75	2.03	4.07	4.07	5.42
P. E.....	.24	.45	.54	.64	.63	1.85	.52	.64	.45	.85

Table 2 gives results of inter-blink periods both when the subjects are 'unoccupied' and when they are reading, as determined by the silent count method. These determinations were made by undergraduate students under less well controlled conditions than desirable and are therefore not reliable, but in this case the subjects were unaware that they were under observation. Each student obtained records of *Ss* observed (usually in their dormitories) both when unoccupied and when reading. Results were obtained for a wide range of ages but in most age periods the number of cases are too small to consider. The results in this table show as a general tendency that in the three age-periods (15–19, 20–24, and 40–74 years) the blinking is more rapid when the subject is 'unoccupied' than when reading, and they show also that the inter-blink period gradually decreases with age. On both of these points they agree with those by Ponder and Kennedy, who found that for a time (usually the first six months) the infant makes no true blink responses and that when these responses first appear they occur very seldom. We need much more complete data on this matter of age effects, and also on the influence of sex. Our results indicate a tendency for women to have a shorter inter-blink period than men, but the cases are too few and the observers too untrained for reliable results. We give them here as suggestive of a further problem. It is well known, and also evident from the study by Ponder and Kennedy, that the inter-blink period is influenced by many other circumstances—dryness of the atmosphere, pressure on the eye-ball, sudden changes in degrees of brightness, changes in auditory stimuli, drug effects, and probably conditions of fatigue, etc., as well as by different kinds of mental preöccupation as shown above. All these factors of which the inter-blink period is a function need investigation.

The blinking rate is so much affected by a multiplicity of factors (both extra- and intra-organic) that much careful work must be done to determine their respective rôles. Even the 'unoccupied' and the 'reading' situations of the *Ss* are very complex and need division into different classes of conditions.

Ponder and Kennedy (1927, 105ff.) found in 50 *S*s of each sex, observed while riding in street cars, an inter-blink period of $2.64 \pm .19$ sec for men and of $5.76 \pm .32$ sec for women; whereas on equal numbers observed in the library they obtained a mean inter-blink period of 11.2 sec for men and of 6.7 sec for women (P.E.s not given). While they found the inter-blink period 'remarkably constant for the individual under constant experimental conditions' (cf. also Blount, 1927, as to animals), they also found that the blinking rate is much affected by different attitudes and 'mental tensions,' being faster with 'externalized attention' than with introspective attitudes. They explain the faster blinking of men than of women in the street cars on this basis, having noted that the women are more given to an introspective 'type of attention,' whereas in the reading room they found the attention of the women "much more externalized than that of the men, probably because the latter tend to study more closely than the former. The continual wandering of attention in the women, accompanied by movements of the head and eyes, constituted, indeed, the whole of the difficulty of the experiment" (106 f.).

Such interpretations must, of course, be checked by very careful and extensive research, as these authors themselves recognize. Both our results and those of these investigators indicate also clearly marked and rather constant differences in blinking rate from one individual to another, even of the same sex and of practically equal ages. The physiological and other factors responsible for such differences are yet unknown but should be illuminating.

In the case of what is known as 'voluntary control' of the blinking process, interesting results appear. Under instructions to "wink as fast as you can until signaled to stop" a marked regularity in rate occurs, the speed assuming a rapidity which is apparently limited only by the refractory phase of the elements involved in the individual *S*. These responses, though voluntary, resemble very closely, both as to rate and regularity, the rhythmic scratch-reflex in decerebrate dogs as determined by Sherrington (1906). The mean

number of winks per second as determined from results shown in Table 3 by nine graduate men is 3.72 ± .13, or, in other

TABLE 3

NUMBER OF WINKS MADE IN IMMEDIATELY SUCCESSIVE TEN-SECONDS PERIODS BY NINE GRADUATE STUDENTS AT MAXIMUM SPEED

Subject	Number of Winks in Successive Ten-seconds Periods										Mean per sec.	σ	σ/m
	1	2	3	4	5	6	7	8	9	10			
A.....	44	41	39	39	35	39	37	37	33	33	3.77	.338	.09
B.....	29	27	46	49	39	41	43	42	44	45	4.05	.691	.17
C.....	46	54	53	51	51	46	49	47	42	45	4.84	.400	.08
D.....	39	42	39	39	38	28	36	37	30	33	3.61	.435	.12
E.....	43	41	39	35	35	34	34	45	36	29	3.71	.490	.13
F.....	32	25	26	28	29	26	21	21	23	23	2.54	.378	.15
G.....	41	36	36	36	33	34	33	—	37	31	3.52	.309	.09
H.....	37	32	33	33	29	26	25	34	29	27	3.05	.413	.13
I.....	45	46	45	44	44	43	43	41	41	43	4.35	.188	.05
Mean...	39.56	38.22	39.56	39.33	37.00	35.22	35.67	38.00	35.00	34.33	3.72	.405	.11

terms, the mean inter-blink period is .269 ± .008. These data were obtained from ten periods of winking as rapidly as possible through a period of ten seconds each, the *S* resting ten seconds between each period. The table shows that the different individuals vary somewhat among one another and that the rate for each *S* is remarkably constant except for a slight cumulative effect of fatigue. The range of the nine coefficients of variability is .05 – .17, the mean being .11 ± .02. These coefficients were obtained by dividing the σ by the mean number of winks per second. They are somewhat too large because of the increasing fatigue effects. Correlation between the ranks in the first and the second series is .91 ± .04; between the first and the last series it is .41 ± .18 (and would have been much higher but for the fact that one subject, B, had not had enough experience to know in the first two series how it 'feels' to go at maximum speed and that he made the 'discovery,' as he said, in the third series, rising then to a speed which placed him among the leaders. When this individual record is omitted the correlation between the first and the last series is .86 ± .08. Be-

tween the ninth and tenth series the correlation is .86 ± .08. When the average of the scores in the first five and those in the last five series is considered the correlation is .74 ± .06. The above experiments were carried out individually by the objective recording method.

The effect of fatigue may be determined by taking the geometrical mean of the decreasing number of blinks per 10-second periods from the first to the tenth series, that is, dividing the tenth mean by the first and taking the ninth root ($\sqrt[9]{34.33/39.56}$). This gives a mean decrease in rate of 1.56 percent in nine successive series of ten seconds each (*i.e* from the middle of the first to the middle of the tenth). The entire decrease in rate from the middle of the first to the middle of the tenth trial (nine periods) is 13.22 percent. These decrements would probable be greater if practice effects—whatever these would be with no cumulative fatigue—were eliminated. Cason (1922) has found an increase with practice in voluntary wink-response time. We hope to study this practice effect independently of the fatigue effect, and the influence of both on the refractory phase. Telford (1929) has shown what seem to be refractory phase effects in such voluntary responses as naming digits, judging the length of lines, and 'simple reaction.'

The self-counting method which was employed on a different group of 16 *S*s—6 men and 10 women college and graduate students—after some practices, gave a mean of 3.65 ± .11 winks per second in 100 seconds of ten equal periods with short rests between or an average inter-blink period of .274 ± .009 sec.[1] These responses were also made 'as rapidly as possible.' In this case the geometrical mean of the decrement in rate of response from the middle of the first to the middle of the tenth period ($\sqrt[9]{36.67/41.11}$) is 1.26 percent. The slightly slower wink-period in this case is probably due

[1] Otto Weiss (1911), by a photographic registration of separate voluntary winks at maximum speed, found for the closure-time of the voluntary wink a mean of .060 sec, for the time that the lid remained closed a mean of .031 sec, and for the opening a mean of .111 sec. The sum of these periods is considerably shorter than our mean wink period in a series of winks made as fast as possible, the difference being evidently due to the refractory phase in our serial responses.

to the self-counting of the winks. Winking at maximum speed when counted by oneself, it was found in our preliminary trials, is very slightly slower than similar winking without such counting; but in this case the majority of the *Ss* are women, who may or may not have a slightly slower voluntary maximum rate than men. This problem is yet an open one. At any rate, the two independent experimental determinations by different methods and on different *Ss* came near enough together to indicate that the difference may be due merely to chance factors. The obtained difference, .07 winks per second is only half of its P.E. These self-counting experiments were all carefully directed in the laboratory by the senior author.

The remarkable uniformity of rate of voluntary winking in the case of each individual throws interesting light on the limitation imposed by the refractory phase, and our results also show that this refractory phase in the wink-activity differs from individual to individual. It would be interesting to determine its relationship to such characteristics as speed of response in other sorts of activity, to degree of intelligence, to conditions of training, and to age and sex.

Another problem for further research along this line relates to the change in the refractory period effected by fatigue, which we have touched in this paper only in a preliminary and tentative manner. Verworn (1909), Dodge (1913), and others have noted an increase in the refractory period with increase of fatigue effects. We tried to have a number of graduate men students and one instructor wink as rapidly as possible through a period of time determined by the point of break down of each subject. The instructions were to start at the signal and "wink as fast as you can, as long as you can without stopping. When you feel that you cannot wink any longer without a rest then stop." The results were recorded on the kymograph drum by the method already described, and the same nine subjects were used. Taking the winks in successive 5-seconds periods (no rest between, of course) we get a mean number of winks as follows: 21.3 $\pm$ .92, 19.1 $\pm$ .61, 15.3 $\pm$ .90, 15.6 $\pm$ .35, and 13.9 $\pm$ .81.

The successive decrements here are 10.3 percent, 19.9 percent, − 2.0 percent and 10.9 percent, the geometrical mean of the four decrements of the 5-seconds periods being 10.1 percent ($\sqrt[4]{13.9/21.3} = .8988$, a loss of 10.1 percent). There was a total decrease from the middle of the first to that of the fifth 5-second period of 35 percent, the loss in 20 seconds. This shows a considerable decrease in what may be supposed to be the refractory period, and is in agreement with the results of Dodge and of Verworn, cited above.

The oncoming of fatigue was very interesting both as reported by the *S*s and as revealed in the objectively recorded responses. A general bodily, especially visceral, disagreeableness was reported, due, in some degree, to short inhibitions of breathing. The records show that as fatigue comes on there are tendencies to irregularity due to short pauses, sometimes lasting nearly a second. In one case the winking was continued through a considerable period of time after fatigue had set in and *S* found that this discomfort had largely disappeared, the processes becoming to a considerable extent automatic; but the record on the drum revealed a series of 'rests' of about .80 seconds duration.

Summary

The eye-wink mechanism is controlled by a variety of different kinds of stimuli, operating singly or (more commonly) in various sorts of combination. The somewhat regular blinks of which one is usually unconscious have been shown by Ponder and Kennedy to be regulated automatically through a 'center' in the striate body. These blinks begin near the middle of the first year of age and gradually increase with age. The rate in women is in general somewhat faster than in men, and it is affected, as is also regularity, by a variety of conditions both organic and extra-organic; but each individual seems to have a characteristic rate when other conditions are somewhat constant. Blinking goes on even if one has a glass eye or is blind; the blink-impulses do not cease at once even when the eyes are closed.

Experiments showed that the number of blinks by a person in a given period can be counted with a high degree of re-

liability, as indicated by the consistency of counts by four different observers who have had preliminary instructions and practice. Counting of one's own voluntary winks under instructions to wink as rapidly as possible checks satisfactorily with results obtained by means of an apparatus which records objectively the several winks on a scale of one-second units. By these two methods it was found that such voluntary winking has a highly consistent rate (variability $\frac{\sigma}{m} = .11 \pm .02$) and a speed of about $3.72 \pm .13$ winks per second, thus resembling the reflex responses obtained by Sherrington on decerebrate dogs. The rate is slightly decreased by self-counting and also by fatigue. This latter is probably due to an increase in the refractory phase. Both voluntary winking at maximum speed and suspension of blinking throw light on voluntary controls, which gradually yield to a weakening of the 'set' for the control effected by verbal stimuli. Voluntary responses of this simple type clearly reveal their social and highly verbal character.

Bibliography

Blount, W. P., Studies of the movements of the eyelids of animals: blinking, *Quart. J. Exp. Physiology*, 1927, **18**, 111–126.

Cason, H., The conditioned eyelid reaction, *J. Exp. Psychol.*, 1922, **5**, 153–195.

Dodge, R., The refractory phase of the protective wink reflex: The primary fatigue of a human nervous arc, *Amer. J. Psychol.*, 1913, **24**, 1–7.

Ponder, E., and Kennedy, W. P., on the act of blinking, *Quart. J. Exp. Physiol.*, 1927, **18**, 89–110.

Sherrington, C. S., *The Integrative Action of the Nervous System*, 1906.

Telford, C. W., The refractory phase in associative and rational responses, 1929. Not yet published.

Verworn, M., *Allegemeine Physiologie*, 5th Ed., 1909, 558 ff., and *Silliman Lectures for* 1911.

Weiss, Otto, Die Zeitliche Dauer des Lidschlages, *Zeits. f. Psychol. u. Physiol. d. Sinnesorg.*, 1911, **45**, 1 abt., 307–312.

(Manuscript received April 26, 1930)

THE CORRELATOR

BY ADELBERT FORD

University of Michigan

The general movement for the insertion of statistical mathematics in psychology, and other biological sciences, has been hastened to a great extent by the use of machines which increase the speed of arithmetical computation. Recently there have appeared several machines for the automatic computation of formulae for correlation. Hull's instrument computes the entire correlation. Seashore's instrument computes the formula to such a position that the remaining amount of work may be done on a Monroe calculator. The Cambridge instrument accomplishes results about the equal of the Seashore instrument.

It is to be noted that these instruments, to date, have worked with Pearson's formula for undistributed data,

$$r = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \cdot \Sigma y^2}}.$$

This equation is undoubtedly the best when we are certain of a linear distribution. Curvilinear distributions appear very frequently in nearly all branches of biological statistics, however, and may often be thoroughly invisible in the raw data tables. The use of the above formula, for an undistributed table, may produce a needlessly low correlation when the use of Pearson's *eta* equation would show a relationship considerably higher. It is for this reason that it is highly desirable to plot distributions before attempting to compute correlations. The Pearson formula,

$$r = \frac{\Sigma xy}{N\sigma_x \cdot \sigma_y},$$

was devised for plotted correlation distributions of two variables. A seasoned research worker, accustomed to the

appearance of correlation distributions, can easily scan the array and decide quite accurately whether it is better to solve for *eta* or *r*. A group of well trained Hollerith machine

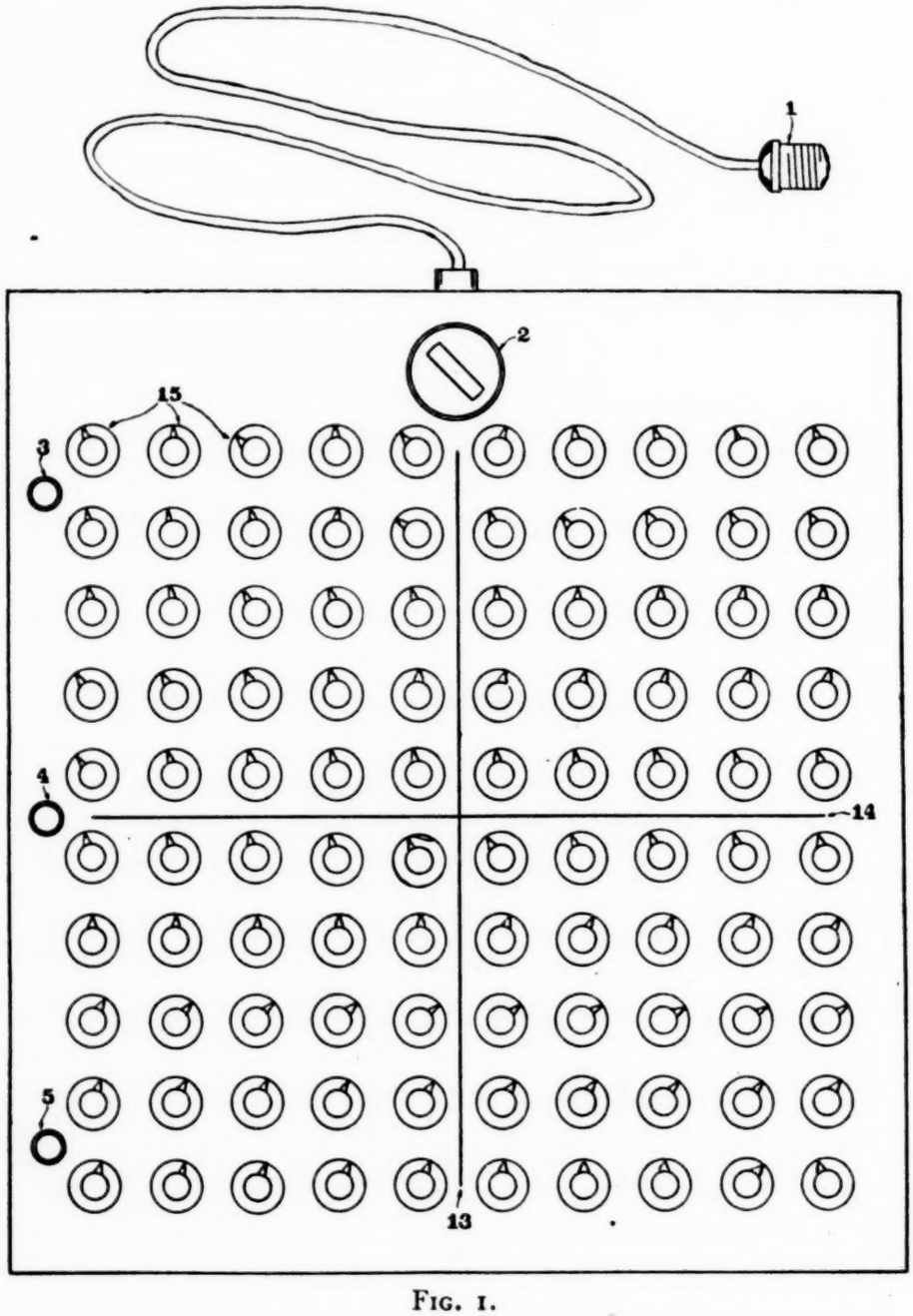


FIG. 1.

operators can prepare several hundred correlation distributions in a very short time. These may be separated into two piles, one adapted to the formula for *r*, and the other adapted to the formula for *eta*.

At the present time we are not aware that there has been any efficient machine method of securing correlations on the basis of plotted correlation distributions, using the second of the two above formulae for r. We have, therefore, devised a method in which each cell of the correlation distribution is represented by increments of physical force or electrical potentials proportional to the number of cases in the cell multiplied by the product of the distances from the x- and y-axes.

Figure 1, a diagram of the outside appearance of the panel, is so constructed that the cartesian coördinates are represented by 100 dials (15), each operating a potentiometer underneath the board. The x-axis (13) and the y-axis (14), establish mathematical lines of reference for each dial used to express the frequency of an appropriate cell in a correlation distribution. The electrical supply to the board is obtained from any source of alternating current electricity through a standard plug (1), being led through the flexible cord to the switch (2). The electrical output of the upper right hand quadrant expresses the value of the products of the positive deviations from the x- and y-axes and is fed to the mechanical indicator through binding posts, 3 and 4. The electrical output of the upper left hand quadrant expresses the value of the sum of the products of the negative deviations from the x- and y-axes and is fed to the mechanical indicator through binding posts 4 and 5, binding post 4 being common to both negative and positive quadrants. The electrical output of the lower left hand quadrant also expresses values of positive deviations and is therefore added in series to the output of the upper right hand quadrant. The electrical output of the lower right hand quadrant expresses negative deviations and is therefore added to the upper left hand quadrant.

Figure 2 illustrates the form of the calibration of the dials, under the assumption that each potentiometer in the machine increases the voltage increment by an equal amount for equal increments of space turned by the dial knob. Since the x- and y-axes are considered to be exactly half way between the two middle columns and rows respectively, that dial which is nearest the intersection of the axes may be regarded

as expressing an x value of ½ and a y value of ½ for each of the units calibrated on its face in an arbitrary manner. The mathematical distance between any contiguous pair of dials, horizontally and vertically, in the entire panel is considered to

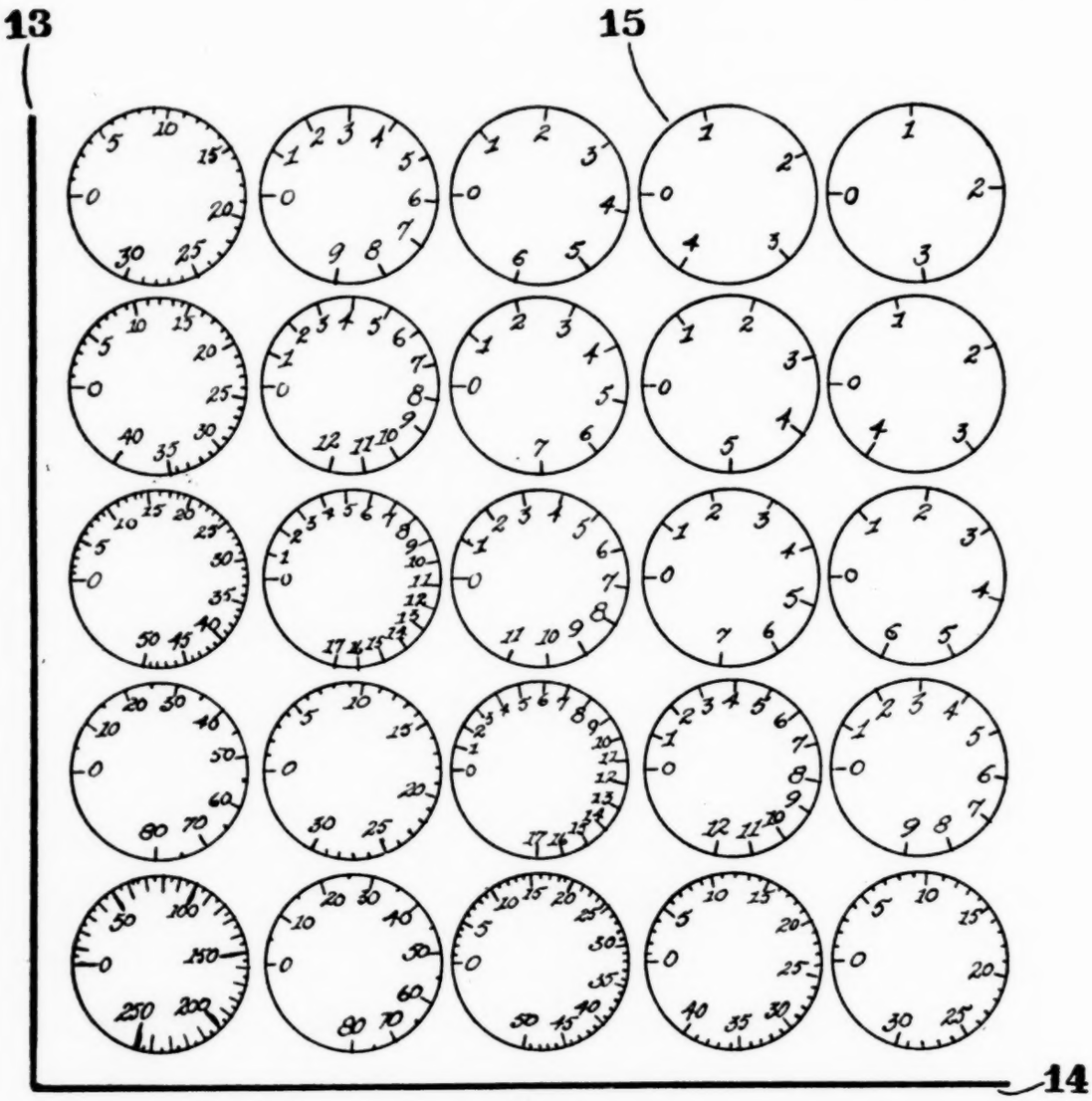


FIG. 2.

be 1. Therefore the value of each unit spaced off on any given dial on the board is equal to the value of the units in the dial nearest the intersection multiplied by the product of the deviations from the x- and y-axes. For example, the extreme upper right hand dial in Figure 2 is 4½ mathematical units from the x- and y-axes. The product of these distances is 8¼

as compared with the dial which is nearest the intersection, which is ¼. Each unit on the extreme upper right hand dial is therefore 81 times as great as a unit on the face of the dial nearest the intersection of the axes.

Figure 3 shows the method of wiring the potentiometers to the current supply and connecting the output current to the mechanical indicator. The primary coil (6) of the transformer is excited by the alternating electrical current from the standard plug (1) in Figure 1. One hundred potentiometers (8) are each supplied with current from a separate secondary coil which is placed inductively in the magnetic field of the primary coil. The voltages established by the secondary coils are equal, which insures that increments of electrical pressure are proportional to mathematical values set on the dials. In general the resistance of the potentiometer elements should be as low as possible, and the resistance of the indicator magnets should be as high as possible, to insure that deflections of the needle will be proportional to voltage. The potentiometers of the upper right and lower left quadrants, keeping the instrument in the same position as in Figure 1, are wired in series in such a manner that the total voltage output of these two quarters will be the sum of the voltages from the separate potentiometers, and will be conveyed to the mechanical indicator through binding posts, 3 and 4, to indicator magnets, 10 and 11. The potentiometers in the upper left and the lower right hand quadrants are similarly wired in series to apply the sum of the voltages through binding posts, 4 and 5, to indicator magnets, 9 and 12. Since each potentiometer dial has been calibrated, as indicated in Figure 2, so that the space moved by the slider for each unit of calibration is proportional to the product of the distances from the x- and y-axes, and since the number of units turned on each dial is proportional to the frequency of the cases in the scattergraph cell, then the total voltage delivered against the indicator magnets, 10 and 11, will be proportional to the value of $+\Sigma xy$ in the Pearson equation; the total voltage delivered to magnets, 9 and 12, will be proportional to the value of $-\Sigma xy$ in the equation.

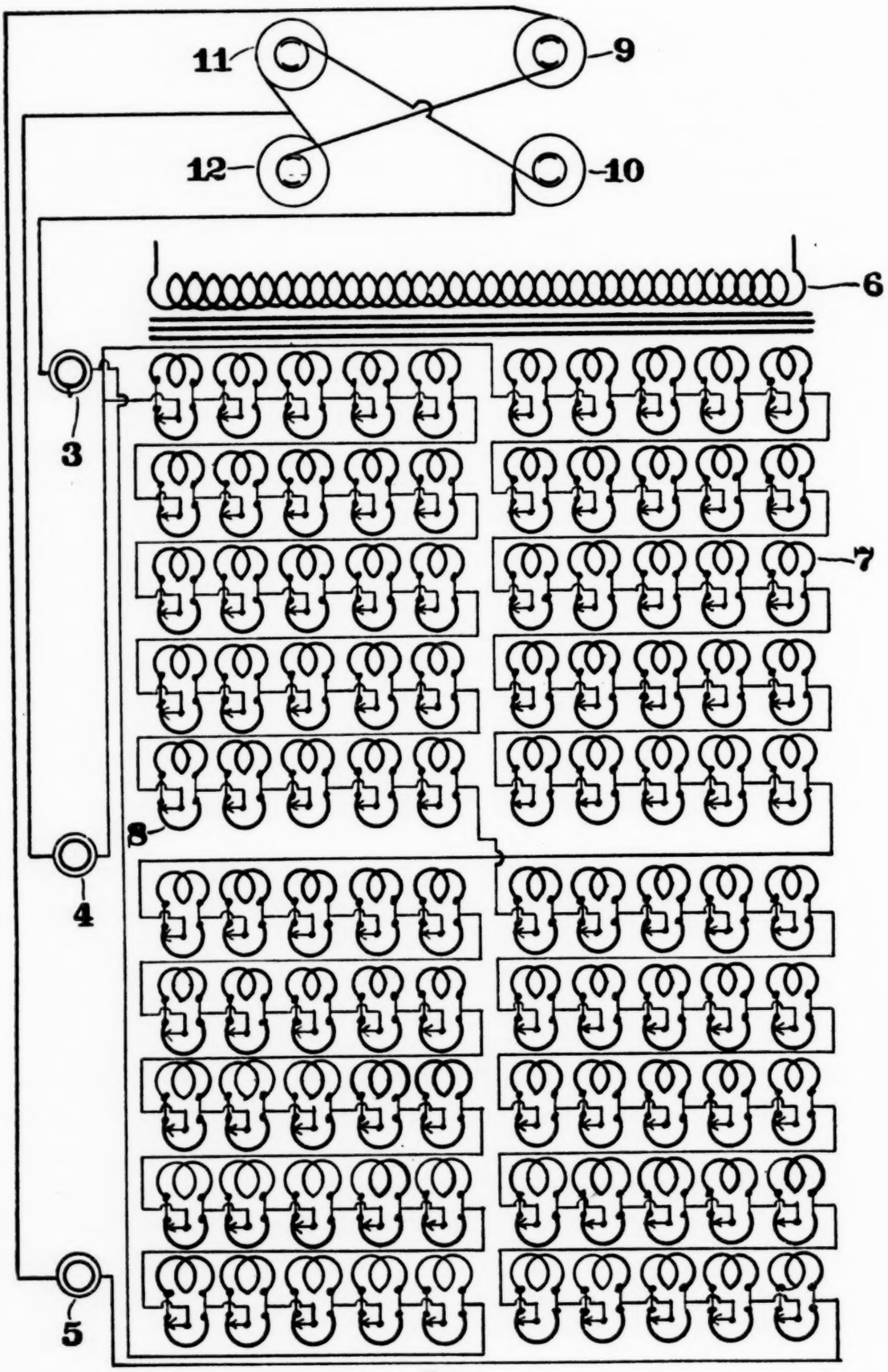


FIG. 3.

Figure 4 illustrates the mechanics of the indicator.[1] The current from the mathematically positive quadrants of the dial board is delivered to magnets, 10 and 11, through binding posts, 4 and 5. Magnets, 10 and 11, are wired in series and their cores connected by a steel strip (17). Magnets, 9 and 12, are likewise wired in series and the cores connected through the strip, 19, which is so bent that it is kept as far as possible from strip, 17, to prevent magnetic losses. A soft iron armature (18) is mounted on a delicate pivot so that it may be attracted to swing in line with either pair of magnets, dependent on the dominance of attraction from either pair. A light aluminum pointer is attached to the armature and swings over a calibrated scale, as illustrated. When the voltage from the mathematically positive quadrants of the board is equal to that of the mathematically negative quadrants, the two pairs of indicator magnets will attract the armature equally; the armature, therefore, points between the two pairs of magnets, a position which indicates that the sum of $+\Sigma xy$ and $-\Sigma xy$ is zero. This position is calibrated accordingly on the scale. When the current delivered from the mathematically positive quadrants is any voltage above zero, and there is no current coming from the negative quadrants, then the armature will swing in line with magnets, 9 and 12, this position being calibrated as $+1.0$. When the current applied from the mathematically negative quadrants of the dial board is any voltage over zero, and the current from the positive quadrants is zero, then the armature will swing in line with magnets 10 and 11, this position of the pointer being calibrated as -1.

Various ideal scattergraph distributions, with known correlation values, are now set up on the instrument, and the scale is calibrated to correspond to the computed values of the tables. Such tables must contain their arithmetic mean, median, and mode, exactly between the two middle columns and rows respectively, and must be symmetrical distributions. Thus, in the Pearson Equation, Σxy is computed electrically in the calibration of the potentiometer dials, while the denominator, $\sqrt{\Sigma x^2 \cdot \Sigma y^2}$, is calibrated into the indicator by the

[1] Suggestions for the mounting of the pivoted armature in this indicator were received from Mr. W. Davidson Harbaugh, assistant in the department of psychology.

use of sample tables. It would be possible to calibrate the entire indicator by a computed mathematical progression,

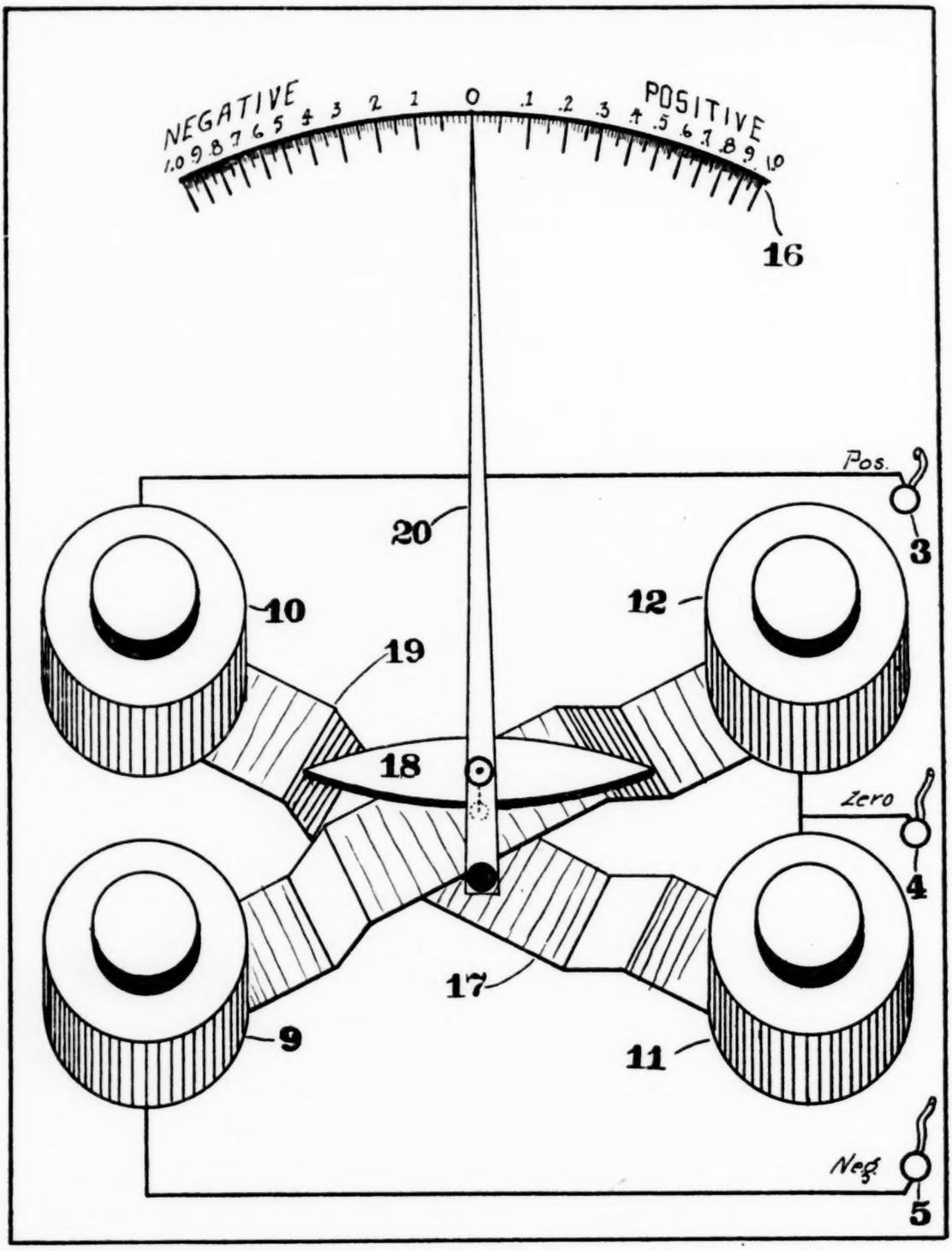


FIG. 4.

except for the fact that variables of an unmeasured type might create errors; the empirical calibration insures that such errors are all taken into account.

The setting up of distribution tables on this instrument requires that the following precautions be taken. The mean of the distribution must fall as closely as possible on a midline between the center columns and center rows. In an approximately symmetrical distribution the mean and the median are identical. If the distribution is not symmetrical, then the regression lines are probably curved and the r formula should not be used. Therefore we may plot the distribution first with rather fine steps, possibly using a 20×20 table. We must know the total number of cases. Then by counting off one half of the cases, by adding column after column, we may determine the position between columns which comes the nearest to the $N/2$ position. Approximately the same procedure is used for determining the median of the rows. The distribution table is now condensed to a 10×10 table by throwing together pairs of columns and pairs of rows on each side of the median. This procedure eliminates the extreme necessity of using a correction factor for the assumed mean, but still leaves an error which will not affect the correlation value by an amount larger than one point in the second decimal place; such an error will be recognized as thoroughly insignificant. The sorting of tables may be accomplished on a Hollerith machine, in such quantities that a large amount of research may be finished in a short time.

At the present time we have made up tables of probable error using an instrument with only a 5×5 distribution arrangement. This rather crude laboratory instrument, using steps admittedly too coarse for accurate results, was used to secure correlation values on 84 tables and the variation of the results obtained from computed values. The average deviation was less than one point in the second decimal place of the correlation answer; the maximum deviation was three points in the second decimal place. On the basis of these tables, an answer which computed .64 might read .61 or .67 on the 5×5 arrangement of the machine, and this only in very exceptional cases. Using the 10×10 arrangement, described above, there is every reason to believe that the errors would be much less.

(Manuscript received April 21, 1930)

A STUDY OF EYEDNESS AND HANDEDNESS[1]

BY NOEL B. CUFF

Eastern Kentucky State Teachers College

I. Introduction

The problem of handedness is essentially one which has to do with bodily asymmetry, with some inequality of the two sides often obvious in the hands and arms. The search for etiological factors of handedness has frequently been directed toward other asymmetries. Some advocates (6) strongly insist that handedness is determined by a larger blood supply to one side of the brain. The explanation, however, claiming consideration now is that of ocular dominance. This theory is protean. Parson (9) has advanced the hypothesis which we shall consider. He does not agree with Gould's (4) assertion that the better eye 'compels the right hand to work with it,' but he presents evidence of a close relation between the dominant hand and the sighting eye. His hypothesis, that the preferred hand is determined by unilateral sighting, is supported by Mills (8) who has used a different and delicate technic for establishing eye-dominance. Rider (11) apparently holds, however, that righthandedness determines right-eyedness. He states that many occupations necessitate accurate sighting and that this cause is more potent in men than in women.

If Parson's conclusion is correct that eyedness causes handedness or if eyedness and handedness are concomitants, both dependent upon the same factor in heredity, a reliable test for eyedness might indicate native handedness. Downey (3) says: "I believe extensive testing will demonstrate that . . . the harmony or lack of harmony between hand and eye, and that the preferred handedness type and the sighting eye are, usually, native traits."

[1] Read at the Twenty-fifth Anniversary Meeting of the Southern Society for Philosophy and Psychology, April 18, 1930, Nashville, Tenn.

It seems that a study of eyedness and handedness will be more valuable than an extensive summary of the numerous opinions relative to handedness, such as may be found in some of the references cited in this investigation.

II. The Problems Considered

The present study has been conducted with three main aims in view: first, to analyze the general meaning of the term eyedness; second, to analyze the meaning of the term handedness; third, to investigate the relation of eyedness to handedness.

When our aims are adequately realized, attacks can be made more effectively on subsidiary problems, such as the significance of sinistrality, of crossed sinistrality, of dextrality, and of crossed dextrality and the relations between such conditions and emotions, intelligence, and school achievement.

III. Procedure and Apparatus

The method used in this investigation was relatively simple. It was necessary to secure a rather large amount of pertinent information concerning the eyedness and handedness of a fairly large number of children. The director and teachers of the Training School at Eastern Kentucky State Teachers College coöperated so readily that it was possible to give tests under controlled conditions. First, routine information, such as name, age, grade, and sex, was recorded on 3 × 5 cards. Second, three tests of eyedness and nine tests of handedness were given to each of the 237 children in grades one to eight inclusive and to 109 college students; making a total of 4,152 tests.

Most of the tests used are well-known. The usual procedure was followed in giving them and they were given in the order listed:

*A*1. Manoptometer.
*B*1. Throwing as an index of unimanual preference. The test was used by Rife (12).
2. Use of the hands in batting (Rife).
3. Use of the hands in sweeping (Rife).

4. Hand behavior in receiving an object.
5. Easy reaching.
6. Energetic reaching.
7. The dominant thumb when hands are clasped with fingers alternating. This test was probably first used by Lutz (7).
8. The foot used for kicking.

C. Hand used in writing.

*A*2. Unilateral winking. This test was used by Rider (11).

*A*1. Manoptometer.

We used in an earlier study (1) the manoptoscope which was invented by Parson to indicate the sighting eye. An analysis of results showed that the device, compared with other methods of testing handedness, represents a certain advance in technic. Nevertheless sources of error were found and the test was criticised. Downey (2) also lists some possible errors. After a consideration of the sources of error, we made the changes in the apparatus which are discussed in chronological order.

The manoptoscope consists of a conical-shaped sighting tube; the wide end is placed against the face like a steroscope and it tapers to a small circular aperture at the other end. The subject looks through the tube at a fixation disc of an exposing device placed 'about two feet in front of him' (9) and indicates which letter, R on the right or L on the left, he sees. We have found that a definite distance is important (1). Downey (2) says, in this connection, "a small group was found who sighted with one eye for far vision and with the other eye for near vision." Hence we attached a small wire to the top of the easel and to the sighting tube so that it would be easy to keep a distance of two feet between them.

It has been found also that at the specified distance of two feet, some subjects saw both letters and one did not see any (1). In view of this fact, we discovered empirically that the sighting tube should taper to a circular aperture of 15/16 of an inch in diameter instead of 1⅛ inches. Such a tube partially solves the problem mentioned.

The letters R and L were placed on separate slides so that they could be moved independently nearer to or farther from the center. This completely eliminated the necessity of having some subjects move nearer to or farther from the easel than two feet.

Since a significant handedness test is likely to be given in most cases to preschool children and to children in the early elementary grades, a small picture of a boy, such as can be found in simple standardized tests, was placed at the center of the exposing device, a picture of a bird was placed on one slide and a picture of a cat on the other. The chance order followed in moving the separate slides toward the center of the easel and the substitution of pictures for the letters R and L have to a large extent met two sources of error mentioned by Downey (2): (1) 'Inaccuracy in following directions, such as a slight movement . . . to bring the object into focus' and (2) 'Voluntary control of the sighting eye, due to expectation or other form of mental set.'

The back of the easel was divided into centimeters which made it possible to secure quantitative results. This change was made because it is generally held that data should be presented in quantitative terms and analyzed by statistical methods.

The departures seem to justify the statement that we have designed a new measuring device. We have called it a *manoptometer* since it can be used to secure quantitative data in studying the phenomena of eyedness and handedness.

Individual differences are revealed by the manoptometer. One first grade child saw the object to the right when it was six centimeters from the center and the one to the left at three centimeters. Another saw the right slide at ten centimeters from the center and the left one at four centimeters. An index of righteyedness was found by dividing the score for the right eye by the score for the left eye; for the first example the index is 200—each index was multiplied by 100 to clear decimals—and for the second it is 250. Such differences are not revealed by Parson's manoptoscope.

The subject was seated at a table appropriate for his age, the easel was placed, in a strong, even illumination, directly

in front of him at a distance of two feet, and he was told to hold the sighting tube with both hands and to look through it with both eyes at the boy. The left slide was moved toward the center and the question was asked: "What do you see besides the boy?" The right slide was then moved toward the center and the question was repeated. The next instruction was: "Watch the boy and say *now* just as soon as you can each time you see the boy and the cat or the boy and the bird." Each slide was moved toward the boy at least four times in a previously determined chance order. In a few cases more than four trials were needed to produce a clear-cut tendency. The median, often also the mode, of the centimeter distances at which the right sighting object was seen was recorded as the sighting score for the right eye and the sighting score for the left eye was found in a similar manner. The manoptometer was used at the beginning and at the end of the group of tests.

Rife's (12) contention that individuals should be classified according to types of dextrality was partially the cause of our using a series of handedness tests. The tests were administered to each subject individually. The child threw a soft rubber ball to the examiner, this was followed by batting (the hand closer to the functioning end of the implement was noted), by sweeping (the hand nearer the floor was noted), by receiving, by reaching for a small box on a table, by reaching for the box when it was so far away that it was hard to reach, and by performing the other activities as listed. The tests were repeated until the common tendency for each test was determined.

The scale devised by Haefner (5) for evaluating tests was modified and used for tests *B*1 to 8 inclusive: a score of 2 for each test in which the right hand was used without exception; a score of 1 if the right hand was used in the majority of cases; a score of ½ if the right hand was used one or more times but not the majority; a score of 0 if the right hand was not used. A score of 16 would mean that an individual is righthanded on 100 percent of the eight tests. Such a scale is rough, but it enables us to obtain an objective measure of handedness.

IV. Results

The results of the tests are recorded in tables I to V. Table I shows the general character of the group studied. Children who performed four activities—writing, throwing, easy reaching, and energetic reaching—or most of the *B*1–8 activities with the right hand are designated righthanded. If the index of righteyedness is over 100 the child is designated righteyed; if the index is 100 the child is listed as equal-eyed; and those who alternated in sighting are called unstable-eyed. There are 120 boys and 117 girls in grades 1 to 8. The data indicate that 93.6 percent of the children and 92.7 percent of the college students are righthanded. The respective percentages of righteyedness are 72.9 and 70.6 and of lefteyedness they are 21.2 and 29.3. If eyedness is a cause or a hereditary concomitant of handedness, we are justified in saying that approximately 20 to 30 percent are natively lefthanded. Statements that from 2 to 6 percent are lefthanded are frequently based merely upon the *existing* condition. Radical differences in methods may account for the large differences in percentages.

Table II gives a brief summary of variations in degree of eye dominance in sighting and of variations in degree of total hand dominance. The indexes of righteyedness show a median for grade 1 of 250 and one for grade 7 of 267. Other quartile scores are also given. The median score for the right hand in grade 1 is 12.1 and for grade 7 it is 13.0. The differences between the percentiles are insignificantly small, this is true too for grades not included in the table, but they show a tendency for the right hand to be more nearly dominant in the higher grades. Those who are called righthanded show wide variations in the total scores which indicate the hand pattern. Righteyedness is, obviously, a fact which varies by gradations from equal-eyedness to an extreme unilateral sighting tendency, the mass of scores cluster around eight centimeters for the right eye and three for the left.

Data presented in table III show that 22 first grade children or 100 percent of the righteyed group throw the with right hand, and that 3 or 27 percent of the lefteyed first grade

TABLE I

GRADE AND SEX OF THE RIGHTHANDED, AND LEFTHANDED GROUPS AND OF THE RIGHTEYED, LEFTEYED, UNSTABLE-EYED, AND EQUAL-EYED GROUPS

Grade	No.	Right-H.			Left-H.			Right-E.			Left-E.			Unstable-E.			Equal-E.		
		M.	F.	Ttl.	M.	F.	Ttl.	M.	F.	Ttl.	M.	F.	Ttl.	M.	F.	Ttl.	M.	F.	Ttl.
1.....	34	11	18	29	1	4	5	9	13	22	3	8	11			0		1	1
2.....	33	17	14	31	1	1	2	11	9	20	5	4	9	2	1	3		1	1
3.....	24	15	8	23	0	1	1	14	7	21	1	1	2			0		1	1
4.....	26	12	10	22	2	2	4	11	9	20	3	3	6			0			0
5.....	33	15	17	32	1		1	13	15	28	2	2	4	1		1			0
6.....	29	14	14	28		1	1	12	10	22	1	4	5			0	1	1	2
7.....	29	18	11	29			0	13	6	19	5	3	8		2	2			0
8.....	29	13	15	28		1	1	11	11	22	2	3	5		1	1		1	1
Total....	237	115	107	222	5	10	15	94	80	174	22	28	50	3	4	7	1	5	6
Percent...		95.9	91.4	93.6	4.2	8.5	6.3	78.3	68.4	72.9	18.3	23.9	21.1	2.5	3.4	2.9	.8	4.2	2.5
College...	109	16	85	101	1	7	8	12	65	77	5	27	32			0			0
Percent...		94.1	92.4	92.7	5.9	7.6	7.3	70.6	70.6	70.6	29.4	29.4	29.3			0			0

children throw with the left hand. There is less agreement between eyedness and bimanual activities; only 32 percent

TABLE II

VARIATIONS IN RIGHTEYEDNESS AND IN RIGHTHANDEDNESS

Percentile	Index of Righteyedness		Score of Righthandedness	
	Grade 1	Grade 7	Grade 1	Grade 7
High	400	500	16	16
75	267	350.7	14.2	14.9
50	250	267	12.1	13.0
25	33.5	29.3	10.4	12.3
Low	17	18	0	8.0

TABLE III

NUMBER AND PERCENTAGE PERFORMING EACH HANDEDNESS TEST AS PREDICTED OR WITH THE DOMINANT HAND

Activity	Righteyed		Lefteyed		Righthanded		Lefthanded	
Grade	1	6	1	6	1	6	1	6
1. Throwing								
No.	22	22	3	1	27	28	4	1
Percent	100	100	27	20	93	100	80	100
2. Batting								
No.	19	21	9	1	18	27	4	1
Percent	86	95	82	20	62	96	80	100
3. Sweeping								
No.	7	13	7	5	7	16	2	1
Percent	32	59	64	100	24	57	40	100
4. Receiving								
No.	20	22	5	1	26	28	4	1
Percent	91	100	45	20	90	100	80	100
5. Easy reaching								
No.	20	21	4	0	25	27	4	0
Percent	91	95	36		86	96	80	
6. Energetic reaching								
No.	19	21	4	0	24	26	4	0
Percent	86	95	36		83	93	80	
7. Clasping thumb								
No.	12	13	9	1	13	14	5	1
Percent	55	59	82	20	45	50	100	100
8. Kicking foot								
No.	22	22	3	1	29	28	4	1
Percent	100	100	27	20	100	100	80	100
C. Writing								
No.	22	22	1	0	29	27	4	0
Percent	100	100	18		100	96	80	
A2. Winking								
No.	9*	17	1	3	13	21	1	0
Percent	41	77	9	60	44.8	75	20	

* Both eyes were frequently winked in the first grade.

of the righteyed in grade 1 sweep righthanded. It is interesting to note that only 41 percent of the righteyed in grade 1 wink the left eye which, a priori, one would expect them to close during monocular vision. Winking may be a more direct measure of acuity than of sighting. Writing, throwing, kicking, reaching, and receiving show the highest agreement with righteyedness. In grades 1 and 6, 100 percent of the righthanded kick with the right foot. The 'throwing test' indicates correctly dominant handedness in about nine cases out of ten, kicking in nine cases out of ten, reaching in eight cases out of ten, and receiving in seven cases out of ten. The dominant hand is not used so often for the other activities. It is evident from the handedness tests that right- and left-handedness are merely descriptive terms for a considerable number of activities, differing in kind and rather specific. Statements have been made in studies of eyedness and handedness that the lefteyed are naturally lefthanded and, even if trained to use the right hand, reveal sinistral tendencies (9) or have 'some residual effect of an inherited tendency to sinistrality' (8). Such an argument is questionable, since table III shows that from 43 to 76 percent of the righthanded sweep lefthanded and that from 25 to 55 percent of the righthanded wink the right eye. Writers who say sinistral tendencies are revealed by the lefteyed should state explicitly the activities referred to and the extent to which they usually indicate handedness.

TABLE IV

NUMBER AND PERCENTAGE OF THE RIGHTHANDED WHO ARE RIGHTEYED

Grade	1	2	3	4	5	6	7	8	College
Male									
No.	9	12	14	10	14	12	12	11	11
Percent	82	71	93	77	93	86	71	85	79
Female									
No.	13	11	7	9	15	10	7	11	64
Percent	76	85	88	90	94	71	64	73	76

Table IV shows that 82 percent of the righthanded first grade children are righteyed. It follows that 18 percent of the righthanded in this grade are lefteyed, equal-eyed, or

unstable-eyed. The percentages of the righthanded whose eyedness does not agree with their handedness varies from 6 to 36. The data show that a larger percentage of the right-handed males are righteyed than is true of the females; this is not indicated by grades 2, 4, and 5.

It is not necessary to present in a table the data which show the association of lefteyedness and lefthandedness. All of the lefthanded children are lefteyed, with the exception of one first grade child who is equal-eyed. All of the males and 71 percent of the females who are in the group of left-handed college students are lefteyed. Quinan (10) has reported 50 percent crossed sinistrality; reports are usually lower than this.

Other data show that 100 percent of the righteyed in this study are righthanded. The percentages of the lefteyed who are lefthanded vary from 62 to 100; the lefteyed groups are, however, too small to justify conclusions.

TABLE V

COEFFICIENTS OF CORRELATION OF RIGHTHANDEDNESS AND INDEX OF RIGHTEYEDNESS

Grade	1	2	3	4	5	6	7	8	College
r.....	.81	.29	−.08	.21	.40	.31	.02	−.02	.17

An attempt was made by the method of correlation to answer in table V the question, are eyedness and handedness highly related or are they relatively independent? The correlations range from −.08 to .81. Some of the *r*'s are not 4 times their probable error and we cannot be certain that a low degree of correlation exists. The first grade correlation of .81 and the other coefficients suggest that the degree of relation may be definitely affected when a child learns to write. Haefner (5) states that apparently a change in hand-writing produces "a modification of the general bisymmetrical pattern in the direction of right-handedness. If this explanation is sound, we must conclude that change in one type of manual activity has definite effects on other manual activities."

Reliability coefficients of .98, .98, and .97 for the two manoptometer tests of grades 1, 2, and 3 respectively indicate a strong probability that the test will get the same results when repeated after a short interval. The reliability is not perfect, but it is higher than it is for many other tests. Obviously the reliability should be studied with other groups and intervals.

V. Conclusions

The data presented in this study, gathered from 4,152 tests of eyedness and handedness seem to justify the following conclusions:

1. The manoptometer enables the experimenter to state pertinent data in quantitative terms.

2. Eyedness is not a form of behavior which can be adequately described by general terms, such as righteyed and lefteyed. The unilateral sighting preference may be much stronger for one righteyed individual than it is for another.

3. Two groups of eyedness exist in addition to righteyed and lefteyed. These are (1) unstable-eyed and (2) equal-eyed.

4. Handedness is a general term used to indicate a number of rather specific activities and is not adequately described by right and left. We have found that from 43 to 76 percent of the righthanded sweep lefthanded.

5. Most persons who belong to the broad type of handedness roughly described as righthanded tend to use—used in from 7 to 9 cases out of 10—the right hand for throwing, receiving, and reaching, and the right foot for kicking.

6. By using a number of activities a quantitative measure of handedness may be obtained.

7. The manoptometer shows that from 20 to 30 percent are probably natively lefthanded.

8. Reliability coefficients of .97 and .98 show that consistent measures are secured with the manoptometer.

9. The validity of the test is indicated by the facts (1) 100 percent of the righteyed children in this study are righthanded, and (2) all of the lefthanded children are lefteyed, except one who is equal-eyed.

10. The scale of handedness shows that 93.6 percent of the children and 92.7 percent of the college subjects are now righthanded.

11. There seems to be a slightly greater dominance of the right hand in the higher elementary grades than in the lower.

12. The correlation between winking and sighting is low. In grade 1 only 41 percent of the righteyed winked the left eye.

13. Crossed dextrals show sinistral tendencies, but one can also state that some dextrals show sinistral tendencies—one may throw, bat, and sight dextrally and sweep lefthanded.

14. The correlations between eyedness and handedness are apparently low with the exception of the first grade r of .81; the range is from −.08 to .81.

References

1. Cuff, N. B., The interpretation of handedness, *J. Exper. Psychol.*, 1928, **11**, 27–39.
2. Downey, J. E., Types of dextrality and their implications, *Amer. J. Psychol.*, 1927, **38**, 317–367.
3. Downey, J. E., Dextrality types and the preschool child, *27th. Yearbook of Nat. Soc. for the Study of Educ.*, 1928, Pt. 2, 153–158.
4. Gould, G. M., *Righthandedness and lefthandedness*, 1908.
5. Haefner, R., *The Educational Significance of Left-handedness*, 1929.
6. Judd, C. H., Ambidexterity and mirror-writing, Monroe's *Cyclop. Educ.*, 1911.
7. Lutz, F. E., The inheritance of the manner of clasping the hands, *Amer. Natur.*, 1908, **42**, 195.
8. Mills, L., Eyedness and handedness, *Amer. J. Ophth.*, 1925, **8**, 1–9.
9. Parson, B. S., *Lefthandedness*, 1924.
10. Quinan, C., Sinistrality in relation to high blood pressure and defects of speech, *Arch. Int. Med.*, 1921, **27**, 257–261.
11. Rider, W., Unilateral winking as a test of comparative visual acuity, *Trans. Opt. Soc.*, 1898, **8**, 434–452.
12. Rife, J. M., Types of dextrality, *Psychol. Rev.*, 1922, **29**, 474–480.

(Manuscript received May 21, 1930)

AN IMPROVED SYSTEM OF KYMOGRAPHIC RECORDING

BY ROBERT G. KRUEGER

Institute of Human Relations, Yale University

The methods used up to the present for psychological recording fall into three groups namely: photographic, smoked paper and ink recording. These methods though fairly satisfactory have decided disadvantages. Photography requires special apparatus including cameras, film, dark rooms and developing equipment. Smoked paper has the advantages of cheapness and of nearly frictionless recording, surpassed in this respect only by photography. The smoking and fixing of the records and their limitation of length to ten feet or so, are disadvantages. Moreover in experimental work it is often desirable to record data over a period of several hours. Ink recording, where ample energy is available, has been the only method suitable for lengthy records. Due to the addition of pen and ink to the stylus the recording friction is increased and small but important movements may be entirely unrecorded. It is evident that a better method of recording is necessary. The writer therefore submits the following.

A few months ago a New York company [1] placed upon the market a new form of recording paper known as Style-O-Graph paper. The paper suitable for psychological recording is produced in two colors, red and blue, and of any length and width. One side of the paper is covered with a thin layer of a mixture probably containing parafine, stearic acid, zinc white and a binder of rosin. The mixture is pure white and when placed upon the paper makes it a light pink. A stylus applied directly to the paper causes the covering mixture to be removed leaving a dark red line. The contrast between the line and its background is ample to make the record easily legible. By sharpening the stylus point a very fine line is

[1] The Stylograph Corporation, Coldwater, N. Y.

obtained. If the record is exposed to excessive handling some blemishes may result because of accidental removal of some of the covering mixture. For all laboratory purposes however, the records are permanent. A pen, pencil or any pointed instrument may be used for writing notes directly on the record.

The paper was given a laboratory trial, but at first was found unsatisfactory because the amount of pressure required for registration produced excessive friction. Where only a small amount of energy is available as in the case of pneumographs and sphygmographs, no tracing could be produced. However, upon drawing a *heated* stylus across the paper, the only pressure being the weight of the stylus, a line appears. With the proper temperature (about 170° F.) and with the paper on a metal kymograph drum to conduct the heat away from the paper, a very satisfactory line results. Reducing the temperature of the stylus results in a very fine line; increasing the temperature results in a wider line.

Three methods of electrically heating the styluses have been developed. (1) Heating the stylus with a coil of resistance wire wound around it (Fig. 1.). (2) Individual radiant heater (Fig. 2). (3) Group radiant heaters (Fig. 3). It is understood that metal styluses must be used in all cases. All three methods were found to be satisfactory. They are shown in Plate I.

Method 1. A 2″ section of the stylus near the point is covered with an insulating material such as mica. Paper was also found to be satisfactory for this purpose since the temperature is not high enough to burn. One end of the resistance wire is fastened to the end of the stylus at *A* (Fig. 1) and the coil wound over the insulating material. The end lead wire (*C*) is insulated and carried to the source of the current, the stylus acting as the other conductor. Wire (*C*) may terminate in a mercury cup in order to prevent the resistance the wire offers in bending. This system is very satisfactory where a sturdy construction is desired. It does not necessitate adjustment, and will stand rather rough usage. The additional weight of the heating coil however, increases the

necessary energy required for recording. To eliminate this difficulty methods II and III were devised.

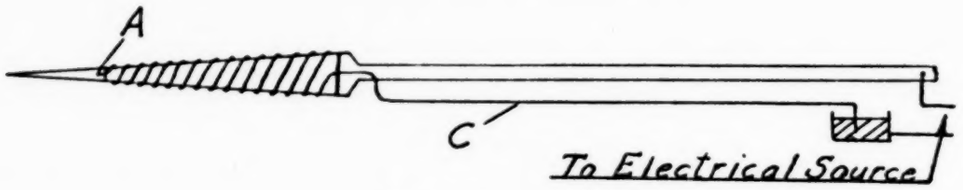


Fig. I

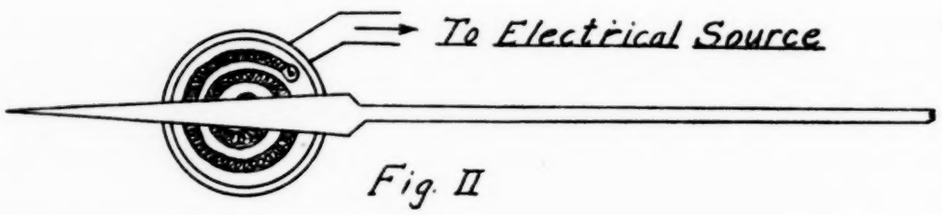


Fig. II

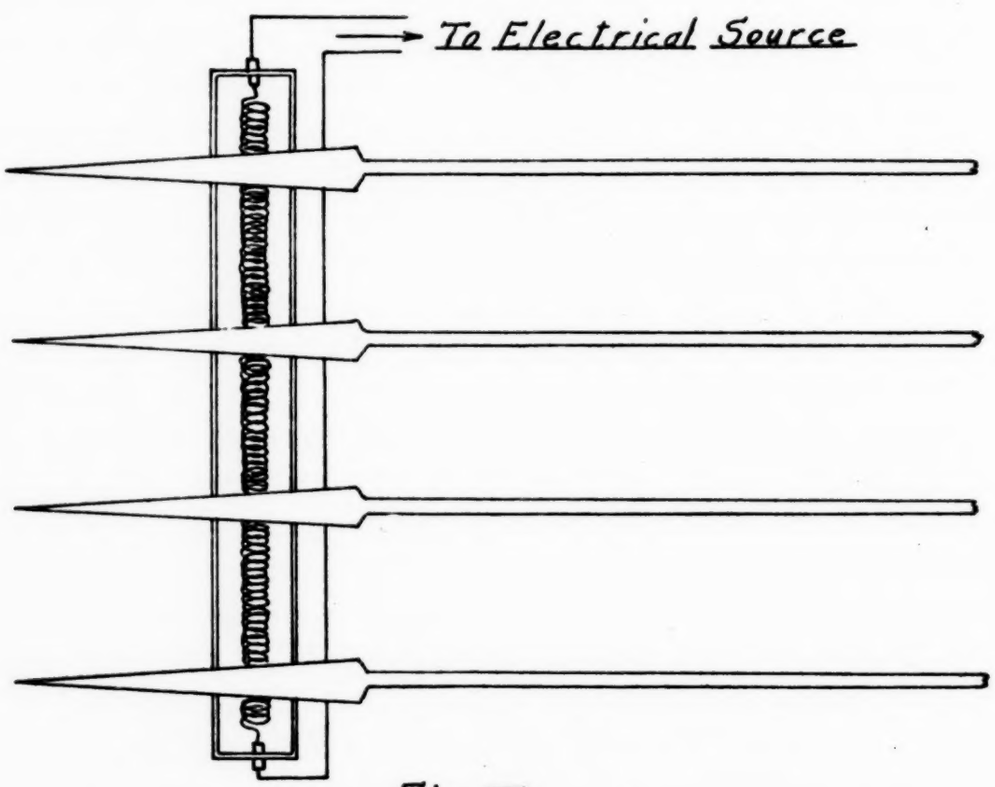


Fig. III

PLATE I. Illustrating methods of heating styluses.

Method II. This consists in mounting a heating element, such as is used in an electric cigar lighter, very close to the stylus and near its point (Fig. 2). The stylus is then heated

by radiation. This method allows the stylus to be absolutely free so far as the heating element is concerned, requiring no more energy for its operation than smoked paper recording.

Method III is merely an elaboration of II. If a group of styluses are to be used, it is inconvenient to have a separate heater for each one. Instead a long narrow heater may be used. The heating unit consists of a metal box about ½ inch wide and ½ inch deep and of desired length depending upon the size of the paper used. A single coil of resistance wire obtained from an electric heater, runs down the center of the box, being properly insulated at both ends. This group heater is moved close to the styluses, near their points and heats them all at the same time. If a stylus should be mounted in such a way that the group heater does not affect it an individual heater may be employed. The source of the electrical energy is optional. The regular lighting circuit with the necessary resistance inserted in series is the most satisfactory.

With the exception of high speed recording of photography, the proposed method combines the advantages of the present methods and greatly minimizes the disadvantages.

(Manuscript received April 24, 1930)

AN APPARATUS FOR RECORDING ELECTRICAL CHANGES[1]

BY HERMAN A. COPELAND
The Ohio State University

With the increased use of electrical apparatus in the psychological laboratory there has been an increase in the need for measuring and recording electrical currents, differences of potential, and the changes of these from time to time. At present one need for such records is in investigating the psychogalvanic response.[2] Since electrical instruments are readily adaptable to many uses, are accurate and dependable, and may be removed from the experimenter without introducing significant errors into the records, it is very likely, as has taken place in other sciences, that other applications of electrically operated devices will appear. The recent introduction into the psychological laboratory of radio tubes, oscillators, synchronous motors, and other machines lends weight to this belief.

Previously one of three methods for recording electrical changes has usually been employed, viz: pen and ink, photography, and electric spark. Some of the advantages and disadvantages of each method will be enumerated. For pen and ink may be said that it is cheap, simple, easily constructed, but its action is slow, as it is affected by friction, and the discovery of a suitable ink is very difficult. For photography may be said that it is not affected by friction, it may be used with extremely sensitive meters, but its original cost, since it must be enclosed in a light proof box, and maintenance, *i.e.* cost of film or light sensitive paper and development of records, and time required for developing which must be done before the records are available are serious disadvan-

[1] The author wishes to express his gratitude to Dr. Stuart M. Stoke of Ohio University where the work was done, for his suggestions and assistance.

[2] Wechsler D., The Measurement of emotional reactions: Researches on the psychogalvanic reflex, *Arch. of Psychol.*, 1925; Vol. 12, No. 76.

tages. For the spark method is claimed the following advantages: record immediately available, apparatus simple, low cost of maintenance, as wrapping paper may be used; but a slight electrostatic attraction, noise of spark, and need for good insulation are disadvantages.

The essential idea of the apparatus to be described is to let a series of (or continuous) high tension electric sparks pass from the pointer of an electric meter through a strip of moving paper, cutting or burning holes in the paper and leaving a record of the deflection of the meter in the form of a dotted line.

The current measuring device is a 0–1 milliameter, which may be shunted by proper shunts for measuring currents of various amounts, or which may be connected in series with various resistances to measure voltages of various amounts. Not only will it measure voltages, but it has the advantage of being a high resistance voltmeter since it has a resistance of approximately 1000 ohms per volt, and hence can be used in situations where the ordinary low resistance (about 125 ohms per volt) instrument would consume too much current.

This meter may be an ordinary one which must be remodeled, or a specially designed instrument (one without case or dial and with a special pointer was secured of the Jewell Electrical Instrument Co.) An adaptation of the three inch minature panel mounting meter may be made without a great deal of trouble, but this will result in the fault of having such a short pointer that the curve may ascend vertically or even slope backward during rapid changes, while the true record should not ascend vertically. This type of meter has been constructed so that the pointer extends over the large permanent magnet, and then the scale is fastened to the magnet. For the present use the pointer is not wanted directed in this way, instead it should extend in the opposite direction. Reversing the pointer is not a difficult task. To accomplish this, loose the moving coil system, and turn it over so that the needle points away from the magnet. If this operation has been done carefully, the meter will function equally as well as before. Then to the pointer should be

fastened 2 or 3 cm of fine (about 30 B.S. guage) platinum wire. This will be found to be most desirable as the spark causes the wire to become white hot at the end and the platinum will not melt. This wire may be insulated from the meter and all high potential currents kept away from the meter. If it is not insulated, the experimenter must be sure that the high tension currents do not injure the construction or operation of the instrument. The author kept this wire insulated from the meter by means of a strip of mica cemented to the pointer with water glass, as neither is readily harmed by heat. This wire is attached perpendicular to the pointer and parallel to the plane of the moving coil in such a way that, should the meter be lying upon a table, the wire would be perpendicular to the table top. Seventy-five millimeters was found to be a satisfactory length for the pointer.

The addition of the wire and mica will have increased the weight of the pointer, and then the weight of the counter-balance must be increased. A coil of fine copper wire fastened to the counter-balance will serve very well. Then to determine if this has balanced the moving system, hold the meter sidewise and in several positions, noting if the pointer remains at zero; if it does, it is balanced. Examination of another meter will usually illustrate a well balanced moving system. It will also be noted that this additional weight will increase the moment of inertia of the moving system making the action of the meter more sluggish, but for many purposes this will not detract from its usefulness.

An objection may be made about electrostatic attraction. If the magnet of the meter is connected to one secondary terminal of a spark coil and the other electrode of the secondary of the spark coil is held in the plane of the swing of the pointer, the attraction will be the equivalent of 0.1 milliampere. This is an error of 10 percent of full deflection, and probably the meter is in error 2 percent originally. In use the attraction will be at a right angle and the effect will be greatly diminished. In practice, when there is no current being measured by the meter, and the spark is passing through the paper, the record is a straight line. It seems, then, that little error is introduced here.

The spark is furnished by a spark coil which may be secured from a scientific or large mail order store. These are sometimes used in spark spectra investigations, old wireless stations, and gasoline engines. The old Ford coil is hardly powerful enough to give a reliable spark. A storage battery, dry cells, or transformer will supply the primary current. Slight variations and suggestions regarding design will be found in the literature.[1,2]

An old spring motor was removed from a phonograph and used to pull the paper between two rollers which were taken from a portable typewriter. Paper was obtained in 250 foot rolls and proved to be rather expensive; later it was found that it could be obtained at barber supply stores at much less cost, though in smaller rolls. An electric motor is recommended as it is adaptable to remote control.

An attempt was made to indicate a time line by allowing an electric spark to burn a hole through the paper, but this was found to be a poor method and is not recommended. The use of pen-pencils of some fashion is probably much better.

It is the opinion of the author that a mechanician could fit this apparatus to the commercial polygraph, and that such an addition may be valuable.

[1] Ford, Recording apparatus: The electro-kymograph, *J. Exper. Psychol.*, 1924, 7, 157.

[2] Lindley, An electro-kymograph used in recording vaso-motor changes, *J. Exper. Psychol.*, 1928, 11, 325.

(Manuscript received April 28, 1930)

APPARATUS FOR MEASURING MUSCULAR TENSIONS[1]

BY J. B. STROUD

Kansas State Teachers College

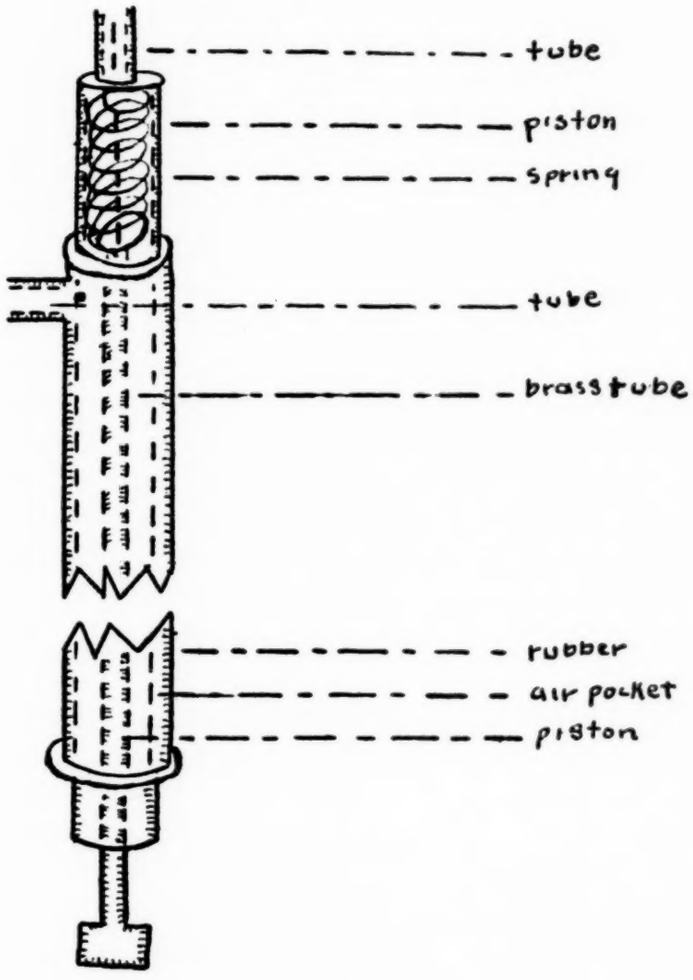
The pressure stylus described herein was designed for use in connection with studies of the role of muscle tensions in stylus maze learning. It consists of a pneumatic attachment which is sensitive to finger pressure, and of a piston effect which is sensitive to the downward pressure exerted upon the maze by the subject. The former works a tambour, the latter operates a lever. One end of the piston works against a spiral spring encased in the topmost part of the stylus, the other fits into the grooves of the mazes. The upper end of the piston is attached to a flexible coil wire cable of the kind used for shutter releases on kodaks. The cable operates a lever by means of which a record of this feature is made upon a drum. The records, in the writer's experiments, were made with recording pens upon continuous rolls of cross-ruled paper. While this stylus was designed for use in studying stylus maze learning it is hoped that, with slight modifications, it may be adapted to handwriting situations.

Incidentally an additional indication of muscle tension was employed. Tambours, set in spring-heads were adjusted, one on either side, to the muscles of the jaws. This seemed to give a pretty fair indication of the tension of these muscles.

The records obtained with the pressure stylus appear to be of some assistance in analyzing learning processes of this kind. The degree of muscle tension, as indicated by this instrument, appears to be correlated with several factors. There is, for example, a positive correlation between the tension exhibited during the various trials and the number of errors made during the trials. Such tension is increased by

[1] From the Psychological laboratory of the University of Chicago. The writer greatfully acknowledges the assistance of Dr. A. G. Bills in making helpful suggestions and placing the materials at his disposal.

artificially inducing tension in other parts of the body. It is suggested that this apparatus gives some measure of the mus-



cle tension present during the learning process and perhaps some indirect expression of such factors as facilitation and effort.

(Manuscript received April 7, 1930)

CORRECTION

Owing to the fact that I left America in February, I did not have the chance to read the proofs for my two articles appeared in the August and October issues of this Journal:

(1) Reading and legibility of Chinese characters: II. Reading half-characters, this JOURNAL, Vol. XIII, No. 4, August, 1930, 332–351.

(2) Reading and legibility of Chinese characters: III. Judging the positions of Chinese characters by American subjects, this JOURNAL, Vol. XIII, No. 5, October, 1930, 438–452.

The following typographical and minor corrections should be made. The printer's inversion of the entire illustration in Fig. I on page 439 is serious but unavoidable, because the characters are in the same consecutive order as that in Table I on page 440 and should be so numbered. Several investigators used Chinese characters in the past as experimental material. But the characters copied by foreigners were necessarily so much distorted that I thought it useful to print some genuine sample characters out of the material used in these reading and legibility experiments.

PAGE	LINE	WRONG	CORRECTION
334		FIG. II.	FIG. I.
345	3	FIG. I.	FIG. II.
347	4	is found to .83	is found to be .83
350	2	1)	l)
351	27	read-	reading
439		*The entire illustration in Fig. I. was wrongly printed upside down.*	*The entire illustration in Fig. I. should be rightly turned right side up.*
443	5	4 M's	4 I's
444	33	4 M	4 I
445	9	Thus, upright (u) characters are judged as upside down (d′) in 26.8 percent of the cases.	Thus, upside down (d) characters are judged as upright (u′) in 26.8 percent of the cases.

BERLIN, GERMANY
29 October 1930

SIEGEN K. CHOU